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HISTORY AND DEVELOPMENT OF THE

DIESEL ENGINE

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HISTORY AND DEVELOPMENT
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I. INTRODUCTION.

Probably no other heat motor has ever received such a rapid development and wide attention by engineers as the Diesel engine. Since its first appearance about twenty-one years ago, the Diesel engine has been built by the thousands in the best factories of all industrial countries, and has been set up in the most remote corners of the world.

Its success is due to the fact that it is the most economical and the simplest prime mover known to-day. It is the simplest because it is an engine which converts the heat of the natural fuel into work in the cylinder without any previous transforming process. When properly constructed the engine has proven to be very reliable, and the working of it quite safe. The thermal or indicated efficiency is as high as 48 per cent, and in some cases a brake efficiency of 35 per cent of the heat value of the fuel has been obtained.

Unlike the development of most heat motors, which have been first constructed and the theory later worked out, the Diesel engine was first worked out in theory by Professor Rudolph Diesel

of Germany and later constructed by him in the year 1893.

Although the first two engines built met with failure, Mr. Diesel learned just what he wanted to know,that pure air could be compressed to such a high point that fuel injected into the cylinder would ignite. It also proved to Mr. Diesel that the practical possibility of carrying out the combustion processes which he had developed so many years before,and which the technical world had regarded impossible,was quite apparent.

The failure of the first two engines,together with the first few years of experimenting,would have been enough to discourage any engineer sufficiently to discontinue the work,but Mr. Diesel had such confidence in the correctness of his mathematical deductions that he lost neither courage nor patience.

The Diesel Theory.

Mr. Diesel devoted about fifteen years of study to the subject of the utilization of heat in gas and oil engines. Starting from the proposition that steam,gas,and oil engines were worked upon a defective principle,and that no improvements in them would produce better results,as long as this principle obtained, Mr. Diesel formulated the theory and conditions he wished to substitute for them.

"The relative low heat efficiency of steam engines is well known. T his is chiefly traceable to the nature of steam,the loss of heat in the boiler generation being 20 to 30 per cent.

The small theoretical heat efficiency of the steam engine due to the sensitiveness of steam to changes of temperature,and its

tendency to condense against the walls of the cylinders, must also be taken into account. For these reasons Mr. Diesel was of the opinion that this cycle could not be much further improved, and that the increase of efficiency in power engines must be obtained by changeing the method of treating the cumbustible. A greater range of temperature in the motor cylinder was also desirable. Since there are physical limits to this temperature in one direction, it must, to give maximum range, be raised in the other, either by increasing the pressure or by cumbustion in the cylinder itself."

"After examining the methods of work in the cylinder of an internal-combustion engine, Mr. Diesel formulated the following principles, which should in his opinion, govern such engines to obtain maximum efficiency:: His propositions are based upon the pure Carnot Cycle, which many of the German authorities think is better realized in the Diesel than in any other heat engine. To construct a motor in which all the heat generated by combustion shall be converted into work is impossible, but the Diesel approximates more nearly to ideal efficiency than does anything ever before found practicable. As is well known, the heat losses in a good gas or oil engine are large, and if an attempt be made to diminish the loss to the cold walls or to the cooling jacket, an increased loss to the exhaust is the result, and no practical gain is obtained. It was first proposed to reduce these losses by isothermal cumbustion at constant temperature, instead of combustion at constant volume or pressure.

This was secured by gradually introducing a small quantity of combustible into a volume of compressed and highly heated air; thus securing spontaneous combustion. The piston is forced out at the same time in such a way that no increase of temperature takes place,becauce the heat developed by each particle of combustion is instantly absorbed by the cooling due to expansion. Any improvements in the cycle of work in an internal-cumbustion engine should,in Diesel's opinion,be carried out in this direction."

To effect them,he laid down the following fundamental conditions for cumbustion:

I. "Production of the highest temperature of the cycle,not by and during combustion,but before and independently of it, entirely by mechanical compression of the air."

2. "Gradual introduction of a small and carefully regulated quantity of finely divided combustible into the highly compressed and heated air,in such a way that no increase of temperature takes place during the motor stroke, but all the heat generated is at once carried off by the expansion of the gases of combustion. (The combustible, Mr. Diesel says,may be gaseous,liquid,or powdered coal,but up to now,oil is the principal fuel)."

3. "Introduction of a large quantity of air in excess,instead of admitting only as much air as is required to obtain proper combustion of the fuel in the cylinder."

Origonally he proposed two other conditions,which have been relinquished for the present. "The air was to be compressed,first isothermally,water being injected to carry off the heat,then

adiabatically, thus embodying the Carnot cycle. This method involved such enormous pressure, from 100 to 250 atmospheres, that it was abandoned, and adiabatic compression only, from 30 to 50 atmospheres, was adopted. The modification is based upon a theoretical diagram in which the two extreme points, that of the maxium pressure of combustion and that of minimum pressure (expansion to exhaust), are cut off. There is pratually no diminution in the area of work, the construction of the cylinder is made simpler, and a working instead of an unworkable cycle is obtained. Further, the second condition for combustion was to be carried out in such a manner that no water jacket was to be required, but it was found that to work without a jacket necessitated much larger dimensions of the cylinder, and for practical reasons a water jacket is now always used."#

However, the idea of compressing air alone in the cylinder, and then injecting fuel into that air, either in a gaseous or liquid state, was not a new one at the date when Mr. Diesel took up his work. In 1887 Mr. Dugold Clarke had built in Birmingham, England, an engine of the two cycle type in which air was sent into the motor cylinder, compressed in the compression space, and a separate pump for compressing gas, forced gas into the cylinder; this gas ignited as it entered the cylinder, producing a constant-pressure type of engine. From a running point of view, the engines were good, but as he could obtain greater economy with explosions, he did not carry the matter further.

#The Diesel Oil Engine"
Engineering (London), Jan. 5, 1900.

Mr. Capitaine also built and patented an engine in 1892, burning pulverized heavy oil injected into the compressed air in the cylinder in a particular way. Mr. Capitaine compressed the air to 12 atmospheres, which was equal to atemperature of 300 degrees centigrade. The indicator diagrams also resembled the Diesel indicator diagrams. Mr. Capitaine claimed that the working principle of the two engines were the same, and that there was nothing new in Diesel's patents which were obtained in 1893. A costly lawsuit followed in which Diesel claimed that his patents called for a compression pressure above the ignition point of the injected fuel. Before this time the ignition point had been obtained after the combustion of the fuel. On these grounds Mr. Diesel finally won the lawsuit. The compression pressure for the Capitaine engine was only about half as great.

What Mr. Diesel claimed as new in his patents.#

I. "The process of converting the heat energy of fuel into work, consisting in first compressing air, or a mixture of air and neutral gas or vapor, to a degree producing a temperature above the ignition point of the fuel to be consumed; then gradually introducing the fuel for combustion into the compressed air while expanding against resistance sufficiently to prevent no essential increase of temperature and pressure; then discontinuing the supply of the fuel and further expanding without transfer of heat.

From Patent Records.

2. "In an internal-combustion engine, the combination with the cylinder and piston, of a valved suction inlet for air, or a mixture of air or neutral gas, a valve fuel feed constructed to gradually discharge the fuel into the cylinder, and means in operative connection with the feed valve for opening the same at the commencement of the working stroke of the piston and for closing the same at a predetermined part of the stroke."

3. "In an internal-combustion engine of the character specified, the combination of a combustion cylinder providing means for gradually introducing fuel therin up to the point of cut-off, a compressor connected with the later and with the cylinder, and an expansion chamber for the exhaust gases."

The Diesel Cycle

"Diesel's original diagram more or less closely resembled Figure I, in which 0-I is isothermal compression, effected by combined mechanical compression and thermal cooling; I-2 is adiabatic compression; 2-3 is isothermal expansion produced by combustion, and 3-0 is adiabatic expansion."#

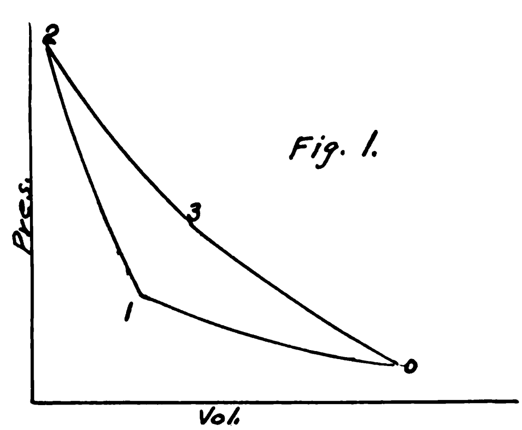


Fig. 1.

#"The new Diesel Oil Engine"
Engineer (London), May 30, 1902.

It was found that this cycle, which is the same as the Carnot cycle, could not actually be carried out in a heat engine; so Mr. Diesel revised the cycle into one which could actually be carried out. This cycle drawn to P-V coordinates is shown in figure 2, in which 0-I is adiabatic compression; I-2 constant pressure expansion produced by combustion; 2-3 adiabatic expansion, and 3-0 heat rejected to cold body or exhaust at constant volume.

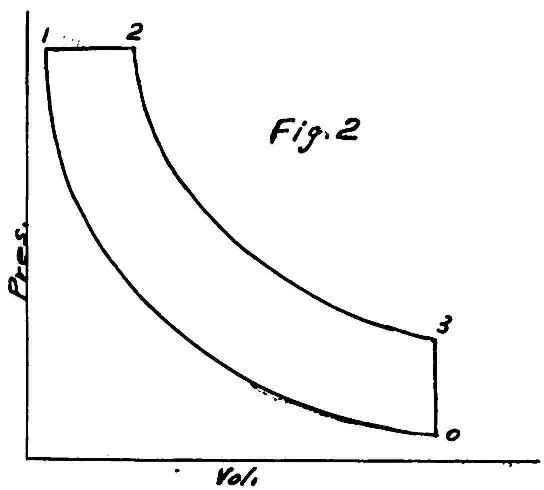


Fig. 2

Proposed Compound Engine.#

"To carry out the principles previously worked out, Mr. Diesel proposed a four cycle process, divided between three vertical cylinders, side by side, the two outer being motor and combustion cylinders, and the inner for compression, expansion, and exhaust. The three cylinders are connected to each other, and to a reservoir of compressed air."

From "The Diesel Oil Engine"...B.Donkin
Engineer London, Oct. 15, 1897.

"The motor plunger cranks are set at an angle of 180 degrees to the crank of the central cylinder, and all three pistons work downwards on to the cranks. Air is first drawn into the central cylinder, slightly compressed, and sent on to the receiver. The two plunger pistons then draw it into the motor cylinders at the top during the first down stroke, and compress it further in the second up stroke to the requisite pressure and temperature.
During the next down stroke (3) the combustible is gradually introduced at the top, and burns as the piston moves out or descends. When the piston has moved through about one quarter of the stroke, the supply of combustible is cut off, and the air and gases of combustion continue to expand. At the end of a stroke a valve at the top of both cylinders opens communication with the central cylinder. The next up stroke (4) of the motor pistons forces the air and gases, still at a considerable pressure, into it; the central piston is driven down, and the air beneath it compressed.
In the return stroke of this central piston the exhaust valve at the top of the cylinder opens and the products are discharged into the atmosphere. The whole process is thus accomplished in two revolutions for the three pistons, or four strokes, and the cycle is similar to that carried out in internal-combustion engines.
By using two motor cylinders in the manner described Mr. Diesel showed that a working stroke is obtained at each revolution."
This engine seems never to have been constructed.

The advantages of this motor are many. The heat is generated in the cylinder so that there are no losses due to passages, and the gases do not condense like steam. On the other hand the

mechanical efficiency must be lower due to the high compression, but many critics maintain that it would be so small as to outweigh all other advantages of the new engine.

Working Diagram of the Two and Four Stroke Cycle Engine.

On page II, Figure 3, is a diagram showing the position for each important event of the four-stroke cycle, and Figure 4, shows the same events for the two-stroke cycle. A comparison of the two and four stroke cycles may be best obtained by studying the diagrams.#

Indicator Diagrams for Single-Acting Diesel Engine.

On page I2,are shown the diagrams of the two and four-stroke cycle Diesel engine. Figure 5,shows the diagram for the four-stroke cycle,in which O-I is intake; I-2 compression; 2-3 working stroke;and 3-0 exhaust. Figure 6,shows the diagram for the two stroke cycle,in which O-I is scavening;I-2 compression;2-3 working stroke;and 3-0 exhaust. In comparing the two diagrams it is seen that the only principle difference is the point of the diagram representing the exhaust. For the four-stroke diagram the point is rounded, while for the two-stroke the point is very sharp.

#Diagrams taken from "The Diesel Oil Engine"
By Rudolph Diesel
Institute of Mechanical Eng.March 15,1912.

Working Diagrams of Single-acting Diesel Engine.

Figure 3.- Four-stroke Cycle.

First Cycle Intake | Second Cycle Compression | Third Cycle Working Stroke | Fourth Cycle Exhaust

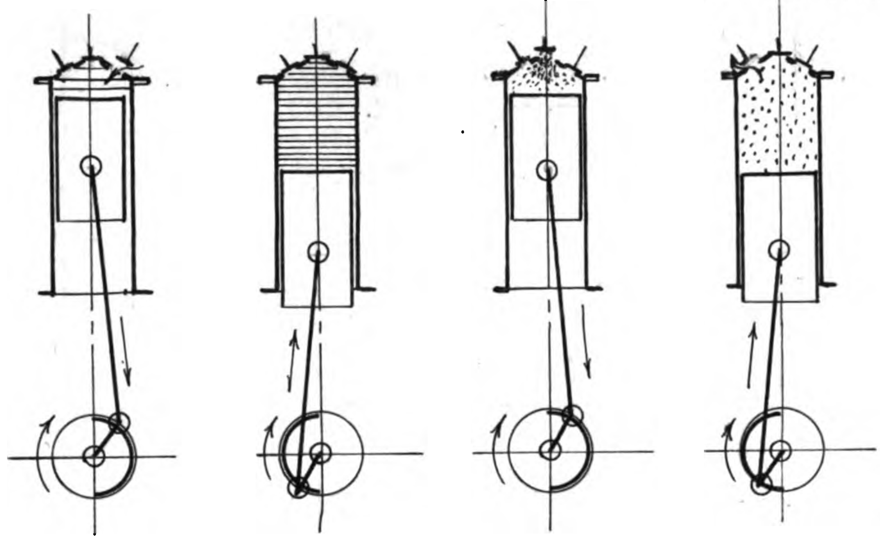
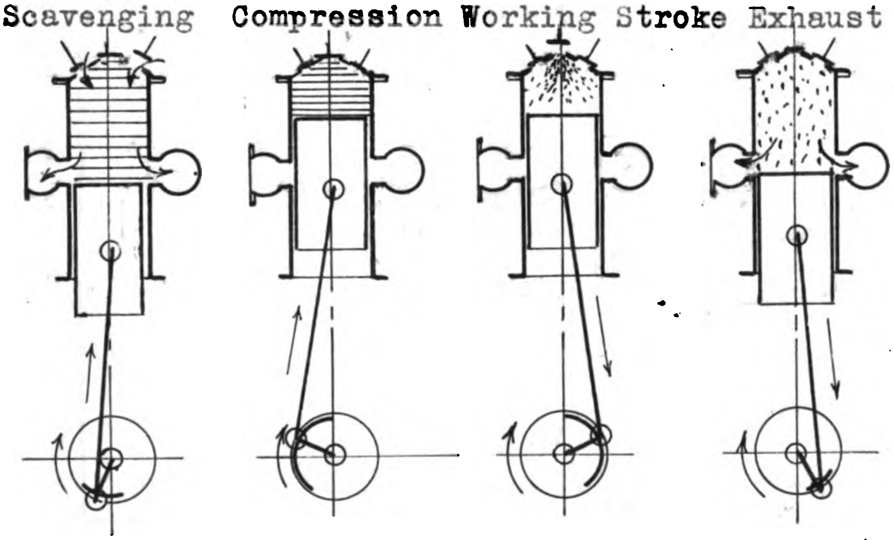


Figure 4.- Two-stroke Cycle.

First Cycle: Scavenging | Compression

Second Cycle: Working Stroke | Exhaust



Inlet of pure air | Compression of pure air | Combustion and Expansion | Expulsion of Gases of Combustion

Indicator Diagrams of Four-stroke Cycle Engine.

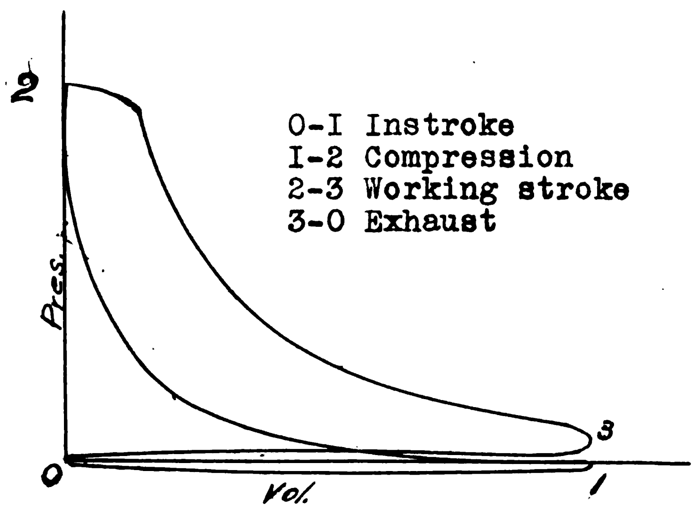


Fig. 5.

Indicator Diagrams of Two-stroke Cycle Engine.

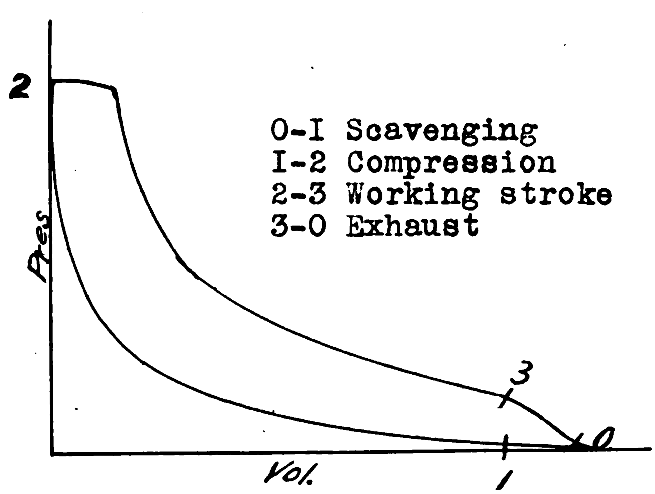


Fig. 6.

HISTORICAL SUMMARY.#

FOUR-STROKE CYCLE ENGINE.

"The first vertical stationary Diesel engine, shown in figure 7, was constructed in the year 1893. It had the piston fitted with a piston-rod and an external cross-head; the cylinder had no water jacket; the cam-shaft was arranged very low, and the valves were actuated by long rods. The starting storage chamber consisted of a wrought-iron pipe with riveted flanges, and there was no air supply pump, the fuel being injected directly. Mr. Diesel never succeeded in running this engine, not even one revolution. The engine was run by mechanical power and at the first injection of fuel a terrific explosion occurred, and the indicator went to pieces nearly killing Mr. Diesel."

Mr. Diesel then built his second engine in 1895-96. It had a base similar to that shown before, but it had a water jacket, and the cam-shaft was placed higher up. "The most important difference was in the air-supply pump for the injection of fuel." The air pump was single acting, but the previous air pump was of a vertical compound type. "The second engine was also a source of danger and would not run; but it ran a few revolutions, just enough to give the first indicator cards." Even though these engines would not run, they proved to Mr. Diesel the possibility of carrying out the combustion he had theoretically developed years before.

The figures shown with their descriptions were taken from "The Present Status of the Diesel Oil Engine in Europe," by Rudolph Diesel.

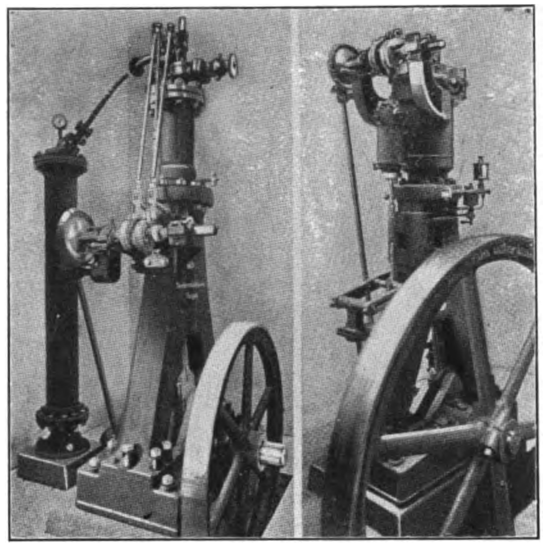


FIG. 7 FIRST TWO DIESEL ENGINES BUILT

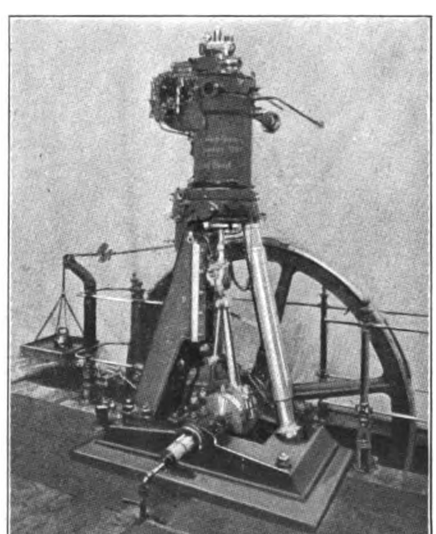


FIG. 8 THIRD DIESEL ENGINE BUILT. VIEW SHOWS TESTING BRAKE

"The first reliable Diesel engine,Figure 8,of 18 horse power was finished in 1897 at Augsburg,after about four years of laborious experimenting." It was a vertical engine having the piston connected to an external cross-head and worked on the four stroke cycle". This type was for about ten years the exclusive and almost the stereotyped pattern for all Diesel engines,which were built in various countries. "In the following year,1898, the first single-cylinder engine of 20 to 25 horse power was built at the Ausburg works." This engine had almost all the characteristic details of the experimental engine mentioned,the only difference being that the experimental engine had the cylinder connected to the base by an inclined column in front, while the latter pattern had the A-frame which Mr. Diesel employed on his first engine. The engine had still the external cross-head and guides. The petroleum-pump was actuated by the cam shaft in the exactly the same way,and was driven in both cases by rocking beams from the cross-head. This engine was the first commercial Diesel engine built.

The first public appearance of the Diesel Oil engine was at the Munich Exhibition in 1898,when the following German firms exhibited engines. The Machine Fabrik Augsburg,showed a 30 brake horse-power single cylinder oil engine driving a pump, Krupp, of Essen, exhibited a 35 brake horse-power engine working a rotary pump; The Maschmenbau Gesellschaft Numberg a 20 brake horse-power engine; and the Gas Motoren Fabrik Deutz, showed a 20 brake horse-power engine. All the engines were of the single cylinder type.

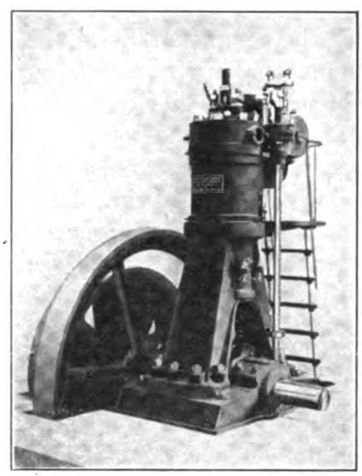


FIG. 9 DIESEL ENGINE BUILT IN 1901

The first two-cylinder engine of 60-76 horse power was made in 1899, in which all details of figure 8, are still to be recognized. "The only alteration, which was made in the year 1901, was the abandonment of the external cross-head and the adoption of the trunk piston shown in figure 9" A comparison of this engine with that illustrated in figure 8 shows that, with the exception of the omission of the cross-head, no alterations of any importance have been made. "Vertical four-stroke cycle engines of from 10 to 250 horse power per cylinder were constructed after this pattern, and units up to 1.000 horse power were obtained by combining several cylinders. "Their weight was origonally from 617 to 771 pounds per horse power, and later this was reduced to 529 to 661 pounds. "This type of engine was used exclusively as a stationary plant for various industrial purposes. Figure 10 shows a two-cylinder M.A.N.# engine of this type of 250 horse power or 125 horse power per cylinder, built in 1902."

A three-cylinder engine of the same type was built by Sulzer Brothers, Germany, in 1906. The two latter engines were altered to drive the petroleum-pump from the vertical instead of from the horizontal cam-shaft, as was the case in the previous engines. The engine built by Sulzer Brothers and by Carels have also a rotating stuffing-box for the fuel needle.

#Mochinenfobrick, Augsburg.

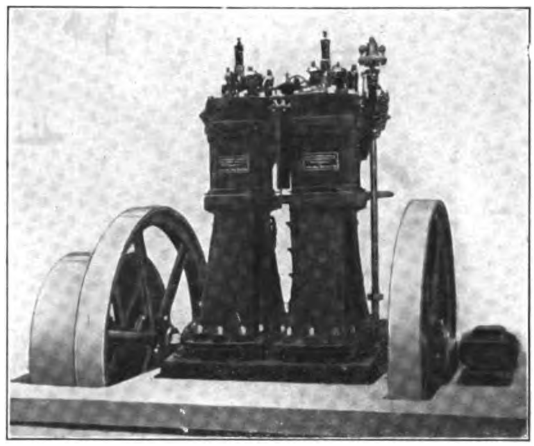


FIG. 10 250-H.P. TWO-CYLINDER DIESEL ENGINE BUILT IN 1902

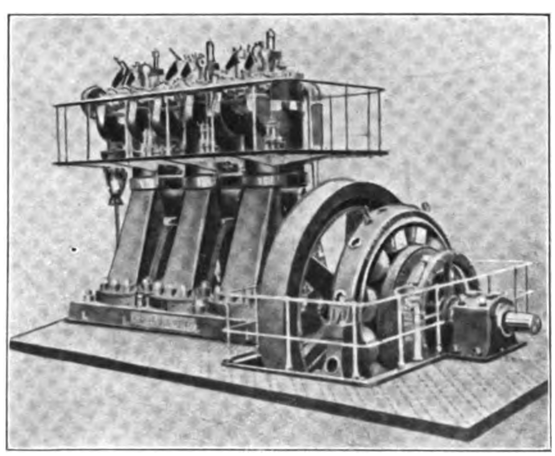


FIG. 11 500-H.P. THREE-CYLINDER DIESEL ENGINE BUILT BY CARELS, EXHIBITED AT LIEGE IN 1905

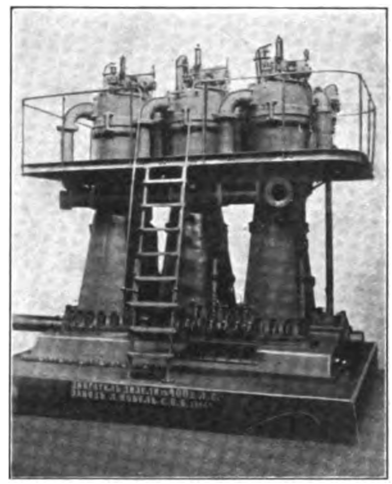


FIG. 12 400-H.P. THREE-CYLINDER DIESEL ENGINE BUILT IN RUSSIA

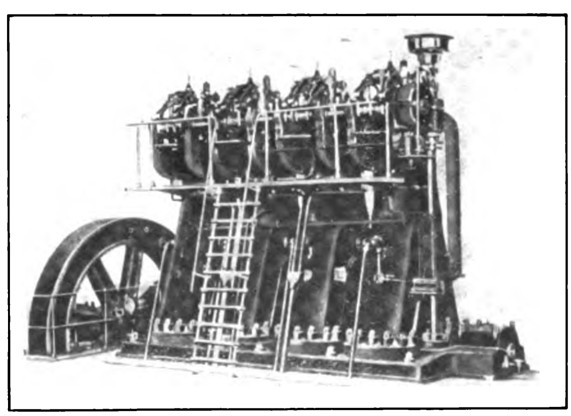


FIG. 13 600-H.P. FOUR-CYLINDER DIESEL ENGINE BUILT BY TOSI IN 1911 AND EXHIBITED AT MILAN

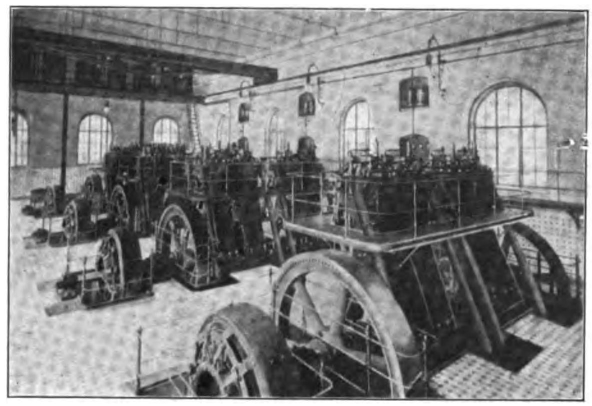


FIG. 14 1600-H.P. DIESEL ENGINE PLANT OF THE RUSSIAN TOWN KIEV FOR THE ELECTRICAL CITY RAILWAY

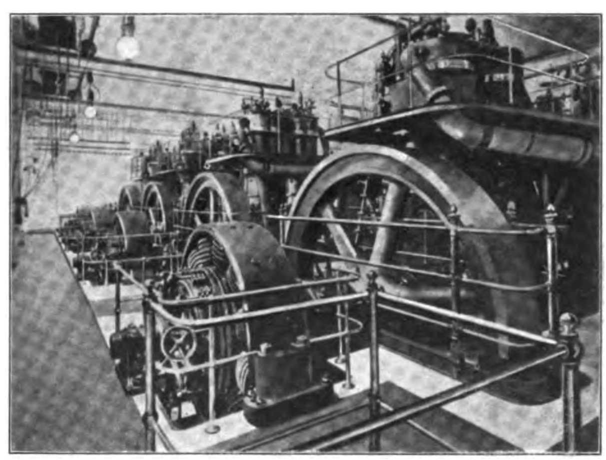


FIG. 15 800-H.P. DIESEL ENGINE PLANT IN THE BASEMENT OF THE TIETZ DEPARTMENT STORE, MUNICH

This arrangement was first built in Sweden and found to work successfully. The 500 horse power three-cyclinder Carels engine, shown in figure II, was exhibited at Liege in 1905. Figure I2 shows a Russian, 400 horse power, three-cylinder engine, Figure I3, a four-cylinder engine of 600 horse power, built in I9II and exhibited at Milan in I9II.

It can be seen from the different figures that the engines built in the various countries still remain almost an exact copy of the old experimental engine, Figure 8, only in America was the design simplified.

In this country the engines were built without cross-heads from the beginning, an idea which, as already mentioned, was followed by European firms in the year I9I0, after the American engines with trunk pistons had proved successful. The Americans also built from the commencement a closed base frame, which has recently been adopted by European high-speed engines. The American engine did not have the fuel valve in the cylinder head, but they were placed in a chamber cast at the side of the cylinder, which necessitated the fuel-needle being placed horizontal between the suction and the exhaust valves.

Finally the American, instead of driving the air-supply pump direct from the engine, always set it up independently, and drove it either by a small extra engine, or by an electric motor. All these alterations were made with the object of cheapening the manufacture, which is a feature in American practice.

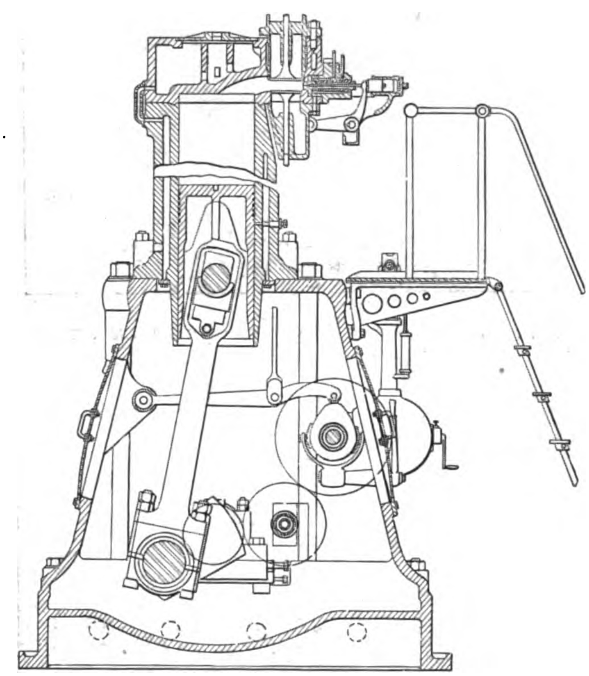


FIG. 16 SECTIONAL DRAWING OF THE AMERICAN DIESEL ENGINE

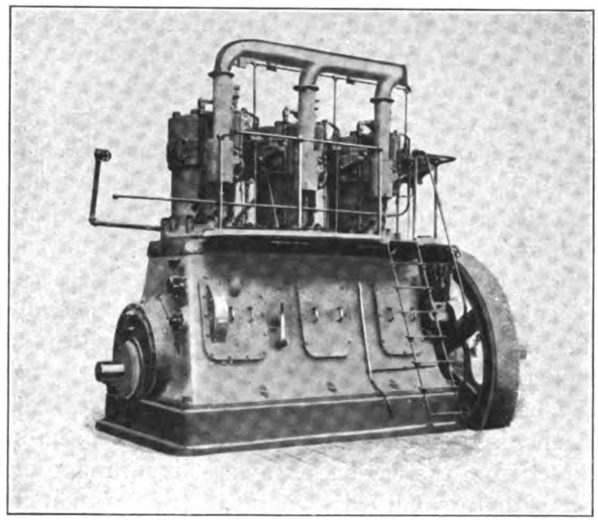


Fig. 17 Outward Appearance of American Diesel Engine

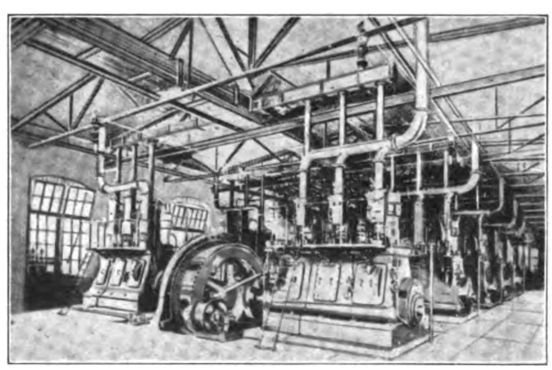


Fig. 18 View of Diesel Engine Plant, Prairie Pebble Phosphate Company, Mulberry, Fla., consisting of Eight Double Units of 450 H.P. Each

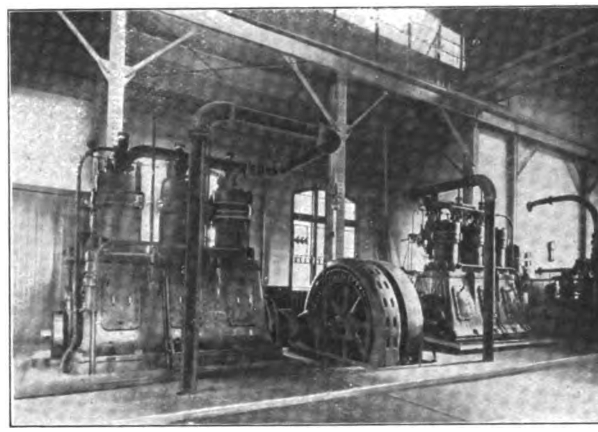


Fig. 19 View of Diesel Engine Plant, Pittsfield Electric Company, Pittsfield, Mass.

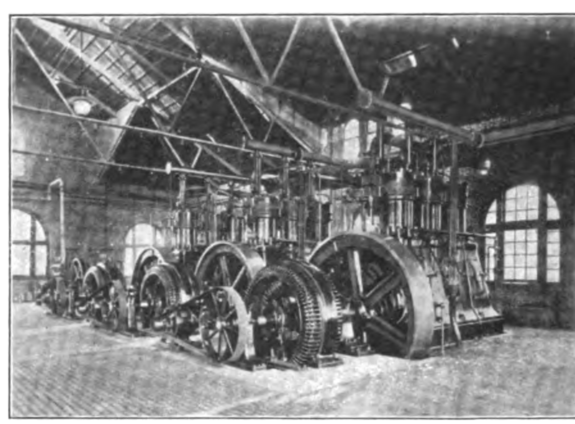
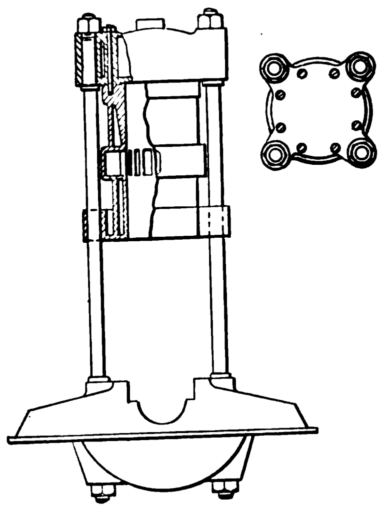


Fig. 20 View of Diesel Engine Plant, United Gas Improvement Company, Philadelphia, Pa.

High-Speed Four Stroke Cycle Engine.

As the central stations took up the Diesel engine early, the necessity for quicker running engines arose. This need, and the improvement in methods of construction, caused a gradual introduction of the quicker running four-stroke cycle engines, with speeds from 300 up to 600 revolutions per minute. The main difference in construction as compared with the first type was that the bearings of the crank-shaft were connected to the cylinder by means of light steel columns instead of heavy cast iron A-shaped frames, so that the cast iron pedestal of the machine became a light crank-case, relieved from great strain. By this means the weight of the engine was reduced to about one-fourth to one-fifth of the weight of the old types, or about 410 pounds per horse power. Engines of this kind are especially suited for driving dynamos, blowers, and centrifugal pumps.

The first of these high-speed four-stroke cycle engines made by the M.A.N. had no alterations from the types previously described. A four-stroke cycle high-speed engine made by Messrs. Sulzer Brothers of Germany in the year 1909, and the older type of engine, differ only in the positions of the air-supply pump, which, in the former case, is fitted to one end of the engine and driven direct from the crank-shaft. This latter kind of engine may be regarded as the final and permanent type of the vertical four-stroke cycle engine for stationary purposes, both for high and low speeds.



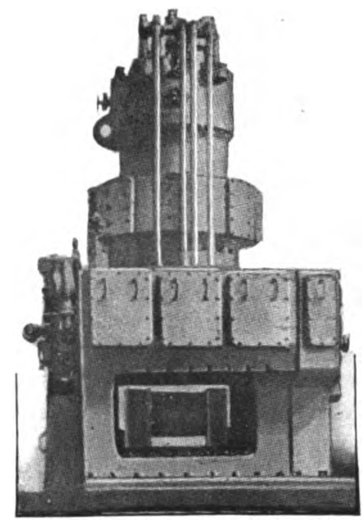


FIG. 34 SECTIONAL DRAWING SHOWING CYLINDER OF 2000 H.P. (DESIGN BY SULZER BROTHERS)

FIG. 35 EXPERIMENTAL CYLINDER UNIT OF 1000 TO 1200 H.P., BUILT BY CARELS

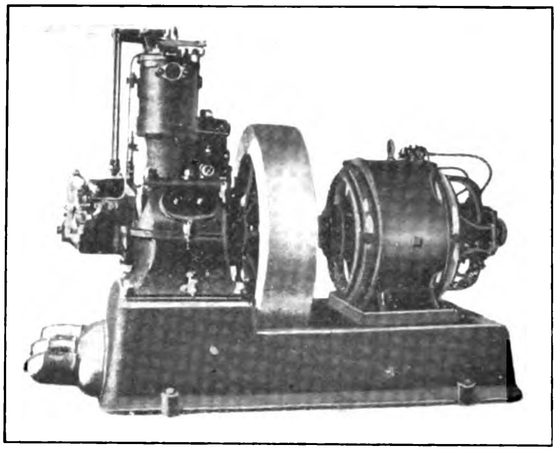


FIG. 23 5-H.P. ONE-CYLINDER DIESEL ENGINE, 600 R.P.M., BUILT IN 1909

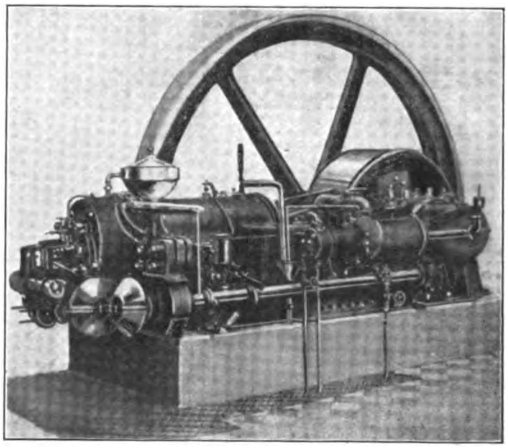


FIG. 24 HORIZONTAL DIESEL-KOERTING ENGINE

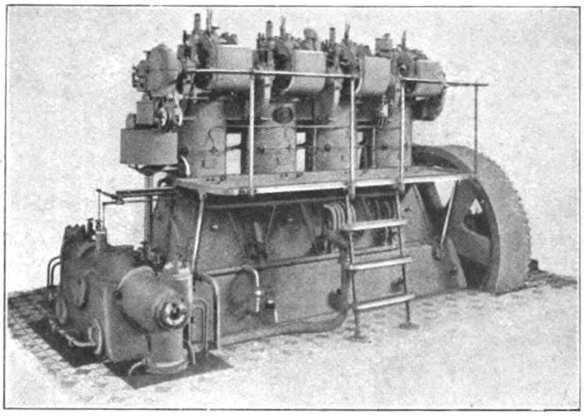


FIG. 21 HIGH-SPEED FOUR-STROKE DIESEL ENGINE BUILT BY SULZER BROTHERS IN 1909

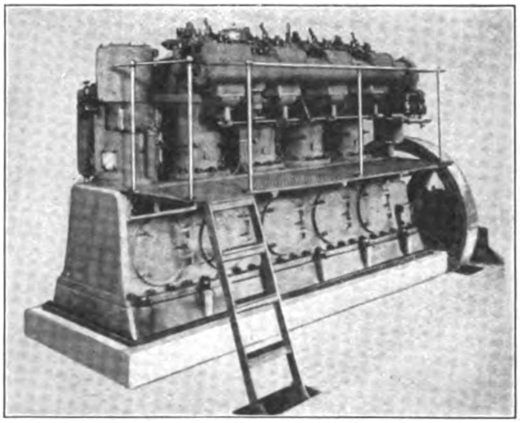


FIG. 22 HIGH-SPEED FOUR-STROKE 350-H.P. DIESEL ENGINE BUILT BY SULZER BROTHERS IN 1911

Horizontal Stationary Engines.

"After vertical engines solely had been used for about twelve years, horizontal four-stroke cycle engines were built." The first horizontal four-stroke cycle engines were practically only vertical engines laid on their sides without any change in design, but gradually the designers freed themselves from the tradition of the vertical engine and some details were altered in such a way that they were suitable for the horizontal position. A type of engine was thus obtained which is hardly distinguished from the horizontal gas engine.

Engines made by the Swiss Locomotive Works, Winterthur, no longer have the inlet valves placed in the cover, but on the side of the cylinder as in the gas engine, and are driven directly from the longitudinal cam-shaft. Only the fuel and exhaust valves are left in the cover. These designs were built for small plants only. The M.A.N. built such horizontal Diesel engines for a very large horse power, as double acting four-stroke cycle engines with two or four cycle arranged tandem. One of the largest engines of this kind, so far, is a double acting, four-stroke cycle tandem twin engine of 1,600 to 2,000 horse power, or 400 to 500 horse power per cylinder with speed of 150 revolutions per minute.

Two Stroke Cycle Engine.

The Diesel principle is essentially suitable as a two-stroke cycle engine, because the scavenging is not done with a fuel air-mixture, but with pure air, so that not only untimely ignition but also fuel losses are avoided, and the scavenging can be done

more effectually and with almost any quantity of air desired.

Working Principle of the Two-Stroke Cycle Engine.

When the piston reaches about nine-tenths of its acting stroke, the exhaust valve opens and the pressure falls rapidly. Then the air-inlet valve, which has a pressure of about four pounds behind it, admits a current of air which sweeps through the cylinder cleaning out the products of combustion, and filling the cylinder with air. The exhaust valve is then closed and the air compressed into the clearance space, ready for the fuel to be injected. During the fuel injection, which lasts only about one-fifth of the working stroke, combustion takes place forming the working or acting stroke again. The power for a two-stroke cycle engine is practically doubled.

The first two-stroke cycle engines on the Diesel principle were built in 1900 and 1901 in Germany and England, but were unsuccessful, because the design of these engines was too closely allied to the two-stroke cycle gas engines, and because the constructional arrangements were unsuited to the Diesel engine.

Successful attempts to construct a two-stroke cycle Diesel engine on entirely new lines have been made within the last few years by Messrs. Sulzer Brothers of Winterthur. To-day this type of engine is on equal footing with the four-stroke cycle engine. For stationary plants of higher horse power the two-stroke cycle engine has come into favor and for margine engines it has become the standard type.

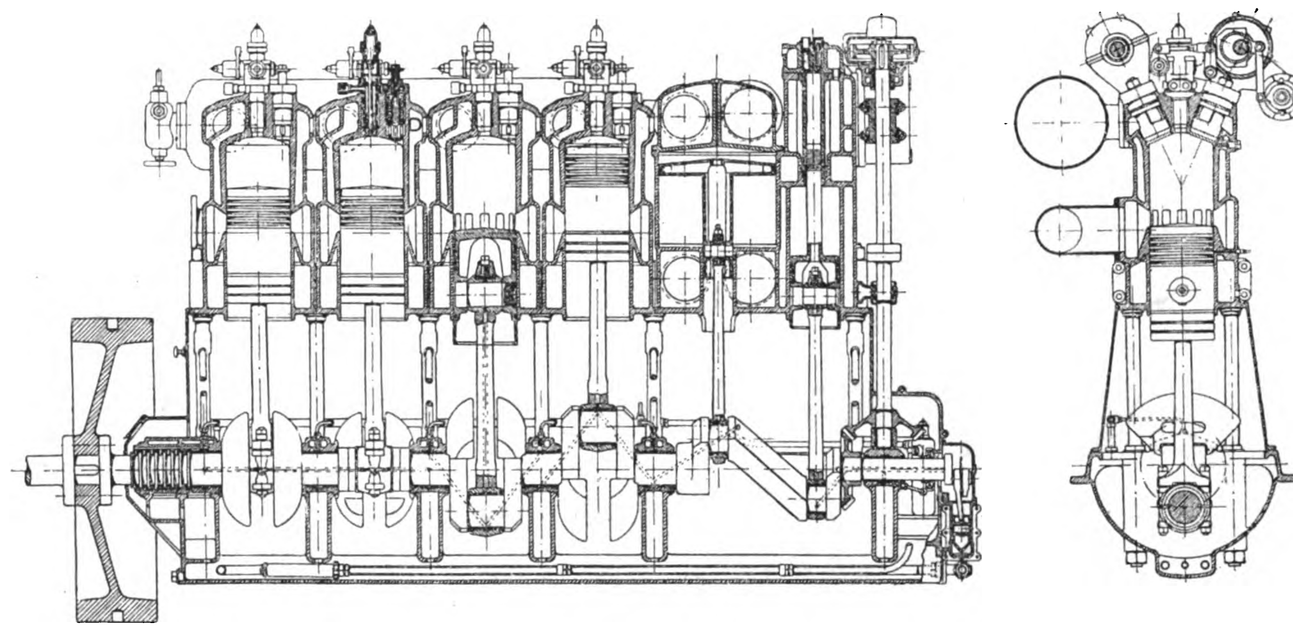


Fig. 26 Sectional Drawing of Sulzer Brothers' Two-Cycle Engine

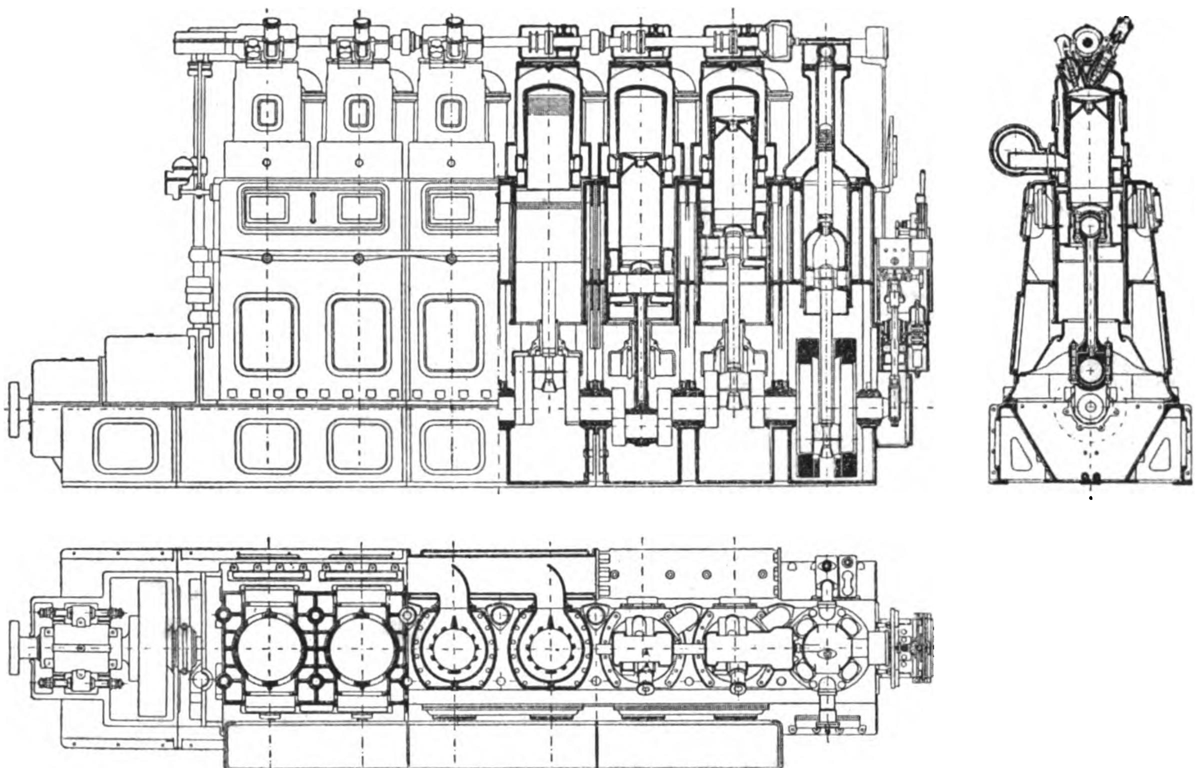


FIG 27. SECTIONAL DRAWING OF MASCHINENFABRIK AUGSBURG TWO-CYCLE ENGINE

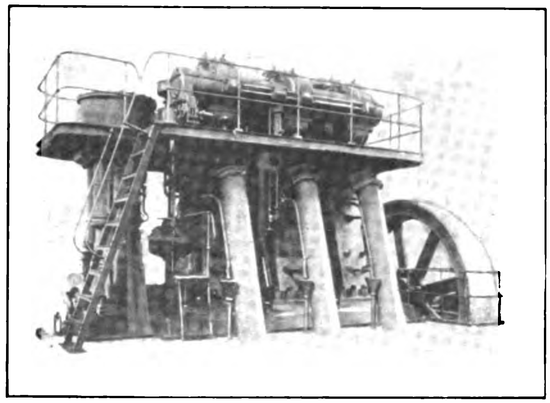


Fig. 28 750-H.P. Three-Cylinder Sulzer Brothers' Two-Cycle Engine (Stationary)

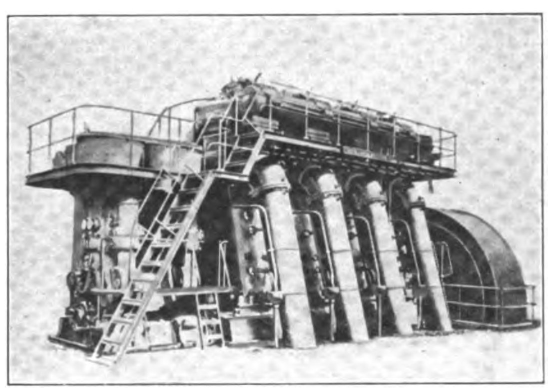


Fig. 29 2400-H.P. Four-Cylinder Sulzer Brothers' Two-Cycle Engine

There are two types of two-stroke cycle engines which have caused considerable competition. The first fundamental type is the engine made by Messrs. Sulzer Brothers, Figure 26,with separate scavenging pump. The second the Maschienenfabrick, Augsburg,or M.A.N. engine,Figure 27,was brought out much later and the scavenging pump,which has an annular piston,is placed underneath each combustion cylinder. Both of these engines are single-acting. A three cylinder 750 horse power Sulzer-Diesel two-stroke cycle engine is shown on Figure 28, and a larger engine of the same type is shown in Figure 29. Two scavenging pumps are necessary for the latter size.

DOUBLE-ACTING DIESEL ENGINE.

The problem of the double-acting Diesel engine was very attractive,but the conditions to be dealt with are much more favorable than with the double-acting gas engine,because of the high pressure. At the present time several double-acting engines have been constructed and found to work successfully. The principal difficulty,the stuffing box,may be regarded as solved. Figure 25,shows a double-acting four-stroke cycle twin engine of 1800 to 2000 horse power per cylinder with 250 revolutions per minute,built by Machienenfabrick,Augsburg.

THE JUNKERS ENGINE.

In the year 1911 Professor Junker brought out a new engine working on the Diesel Principle. This engine works on the Diesel cycle and is a two-stroke cycle type. Its method of operation is represented in Figures 26-30. "The cylinder is open

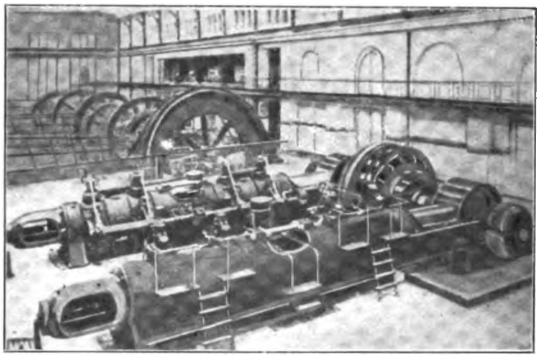
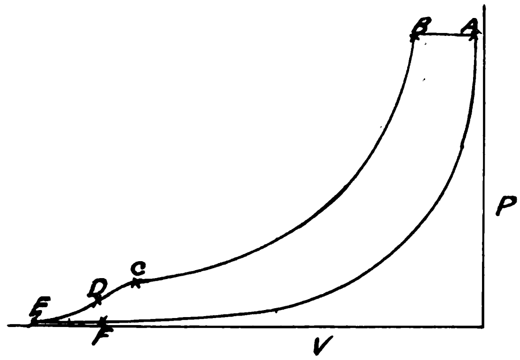


FIG. 25 DOUBLE-ACTING FOUR-STROKE TWIN ENGINE OF 1800 TO 2000 H.P., OR 400 TO 500 H.P. PER CYLINDER, 250 R.P.M., BUILT BY MASCHINENFABRIK AUGSBURG

at both ends and contains two pistons which are linked with a three-throw crank shaft,permitting them to move in the opposite directions. In Figure 26,the pistons are shown in their inner dead center,the space between them being filled with highly heated air as a result of the previous compression stroke. In this position the fuel (oil) is injected in a fine spray,igniting and burning under constant pressure during the first part of the outward stroke from A to B,of the working diagram. From B to C, the expansion of the burned gases takes place,and at C, the pistons have reached the positions indicated by Figure 27,in which the front piston V, is just beginning to open a series of slots or ports,permitting the burned gases to exhaust into the atmosphere. When the position shown in Figure 28, is reached,the equalization of the internal pressure with that of the atmosphere is almost completed.

"Simultaneously the rear piston H uncovers its series of slots. This scavenging is continued until the pistons have passed the outer dead center,Figure 29, and taken up the piston shown in Figure 30. At this instant both rows of slots are closed by the pistons traveling toward their inner dead center, a distance which is represented by E-F, in the diagram. At the point F. the cylinder is filled with fresh air cut off from the atmosphere. As the pistons approach one another in traveling toward the inner dead center (F-A in the diagram) the contents in the cylinder are compressed and heated to a degree such that the fuel injected shortly before point A is reached ignites and the cycle is repeated."



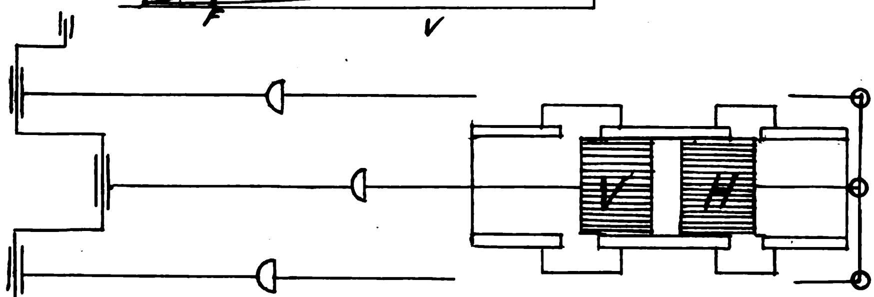


Fig. 26!

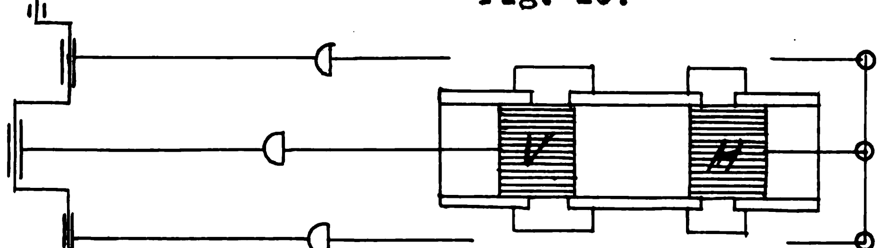


Fig. 27!

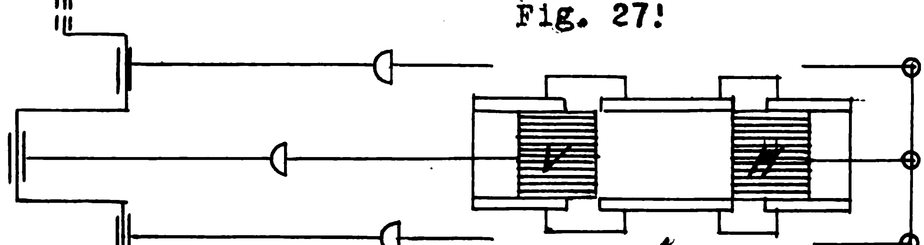


Fig. 28.

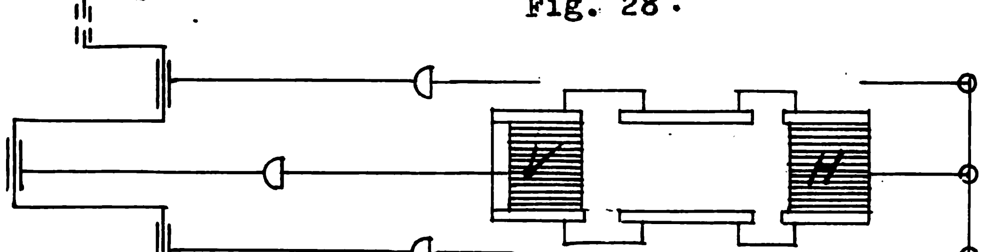


Fig. 29.

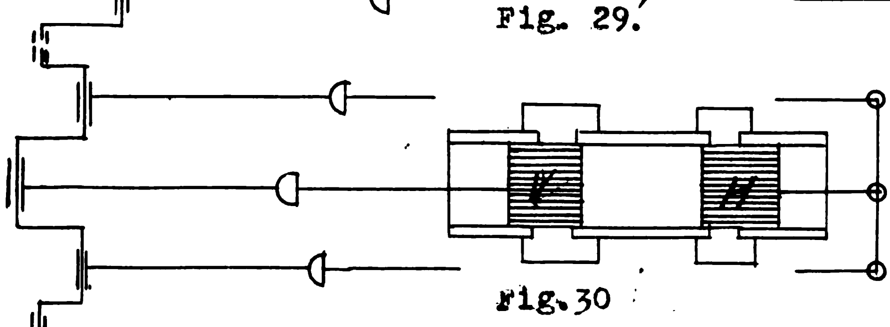


Fig. 30

Figures 26-30.

Junker's Engine.

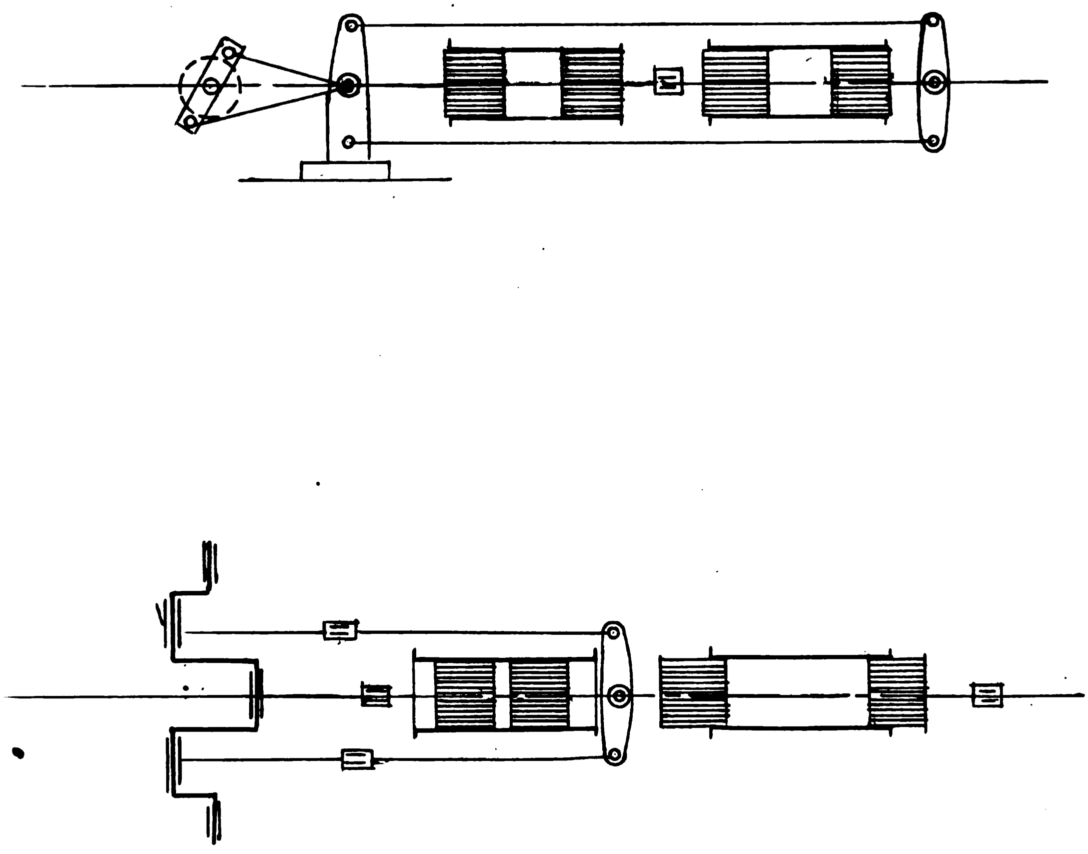


Fig. 3I. Piston and crankshaft Arrangement.

"For large work the tandem arrangement is used,which reduces cost,weight,and space of the engine per unit. On this arrangement a three-throw crank is used,the two outer pistons being linked with the central crank,and the two inner ones to the side crank,which are placed 180 degrees to the former.
This arrangement is shown in Figure 31. By this arrangement each stroke is a working stroke. While the pair of pistons in one cylinder are executing an outward movement(power stroke) the pair in the other cylinder are traveling toward each other, (compression stroke). When the piston in one cylinder occupies the inner-dead center,those of the other cylinder take up the outer dead-center positions. In this way, while fuel injection is going on in the one cylinder,scavenging is going on in the other. The scavenging is accomplished in the same way as in the single cylinder engine."#

Marine Engines.

"The first marine engine was constructed in 1902-3 in France, for use on the canal boats." This engine had,like the Junkers' engine already mentioned,two pistons working in oppositite directions in one cylinder. The fly-wheel shaft was not at one end of the cylinder as in the Junkers' engine,but traversed a cooled chamber passing through the combustion chamber. The engine worked on a four-stroke cycle. A great feature of the engine was the high speed which was made possible by the perfect balance. This engine worked quite satisfactorily. Other engines of various sizes were built for some French submarines.

#From "German Progress in Large Oil Engines."
by F.E. Junge,Power Oct.22, 1912.

Since 1903 the evolution of the Marine Diesel engine has steadily continued. The high-speed four-stroke cycle before mentioned,which were built for electric power stations,were made use of. They were made lighter than before,and used on French submarines and Russian river vessels. These engines origonally were not reversible;but they were used for generating electricity by means of which,the propellers were driven indirectly for maneuvering. In some cases,the propulsion of the vessel was performed directly by the engine,while the maneuvering and slow driving were done by means of electricity.

"The first reversible marine two-stroke Diesel engine,shown in Figure 30, was built in 1905 by Messrs. Sulzer Brothers at Winterthur. At that time engineers were not quite clear as to the importance of the two-stroke cycle principle,and firms went on trying for many years to make the four-stroke cycle engine reversible. The first engine of this kind was built in 1908 by Messrs. Noble Brothers at St. Petersburg,and was fitted to a Russian submarine." It was a three cylinder engine of 120 horse power. The engine is shown in Figure 31.

Great mechanical complications were at first caused by reversing of the four-stroke cycle engine. This problem has recently been solved in a much simpler way,in a six-cylinder 150 horse power reversible four-stroke cycle engine of 350 revolutions,constructed by the French firm,Messrs. Delaunay-Belleville,in the year 1911. This engine is fitted with two air pumps,of which a spare one is for maneuvering.

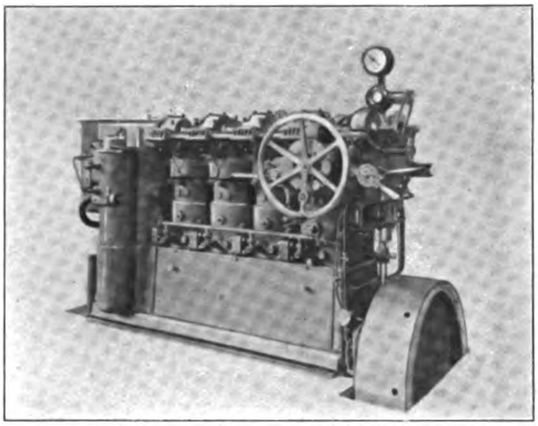


Fig. 30 First Reversing Two-Cycle Diesel Engine, built by Sulzer Brothers in 1905

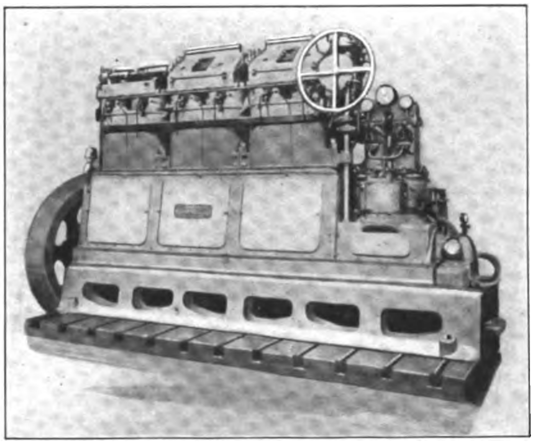


Fig. 31 120-H.P. Three-Cylinder Reversible Marine Engine

The reversible four-stroke cycle engine is still being built, but it is gradually giving way th the two-stroke cycle engine for navigation.

"Figure 33,illustrates the two-stroke marine engine built by Sulzer Brothers,which is one of the standard types for smaller and medium sized marine engines." The engine has six cylinders working at 300 revolutions per minute,and instead of having the scavenging valves fitted on top within the cover,they are placed below in the scavenging air-reservoir.

Within the last few years several high power marine engines have been built. These are mostly of the single acting two-stroke or double acting two-stroke type. Figure 35, shows a cylinder unit of 1000 to 1200 horse power built by Messrs. Carels. These larger engines have only been constructed within the last few years,so they are still in the experimental stage.

An idea of the rapid development of the Marine Diesel engine may be obtained from the table given below. These figures given are only approximate up to the year I9I2.# Since then the development of the marine engine has been even much greater.

Oil Tank Vessels	30
Tugs	40
Motor Sailing Vessels	I0
Merchant Vessels, Freight, Passenger Combined	50-60
Fishing Boats	I5
Submarines (amomg them I7 U.S.Navy Submarines)	I40
Smaller Warships, Cruisers, Gunboats, Ect	40
Small Marine Crafts	20
Micellaneous	20
Total	365-375

#From "Present Status of the Diesel Engine in Europe" by Rudolph Diesel.

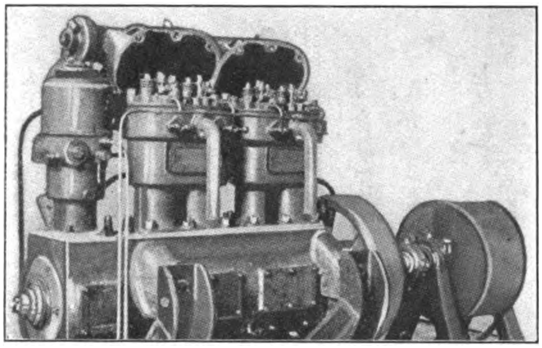


FIG. 32 30-H.P. FOUR-CYLINDER 600-R.P.M. FOUR-STROKE DIESEL ENGINE, BUILT IN 1909 EXPERIMENTALLY AS AN AUTOMOBILE ENGINE

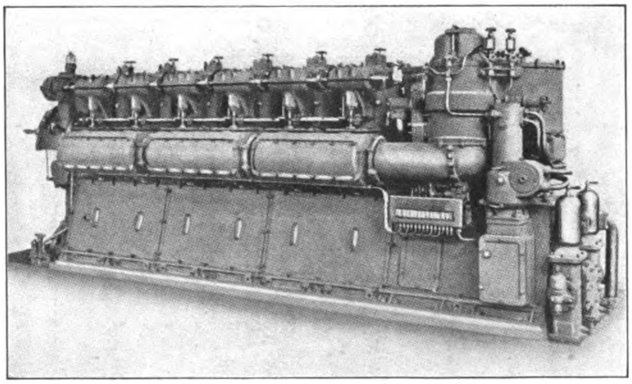


FIG. 33 LATEST TWO-STROKE REVERSIBLE MARINE ENGINE BUILT BY SULZER BROTHERS

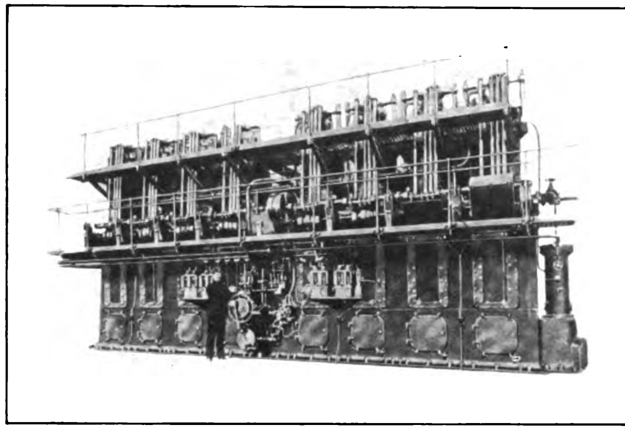


FIG. 47 VIEW OF ENGINE ON BOARD *Selandia*

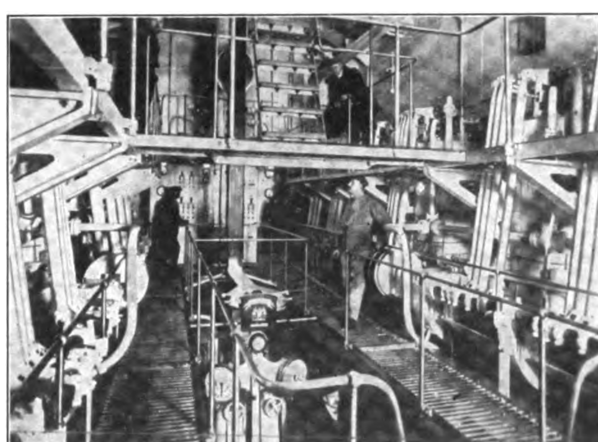


FIG. 48 VIEW OF ENGINE ROOM ON BOARD *Selandia*

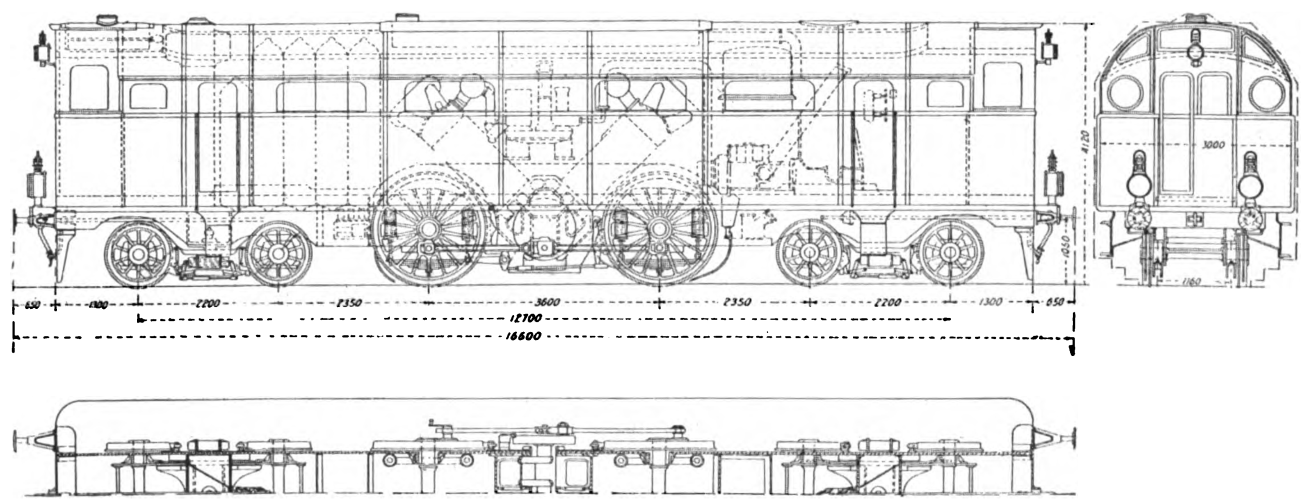


FIG. 49 SECTIONAL VIEWS OF DIESEL LOCOMOTIVE

AUTOMOBILE ENGINES.

The first Automobile engine was made in the year 1899 for experimental purposes by Mr. Diesel, and designed for heavy trucks. Another experimental engine was built in 1909. Figure 32, shows this engine. It is a four-stroke four-cylinder reversible engine of 30 horse power and runs at 600 revolutions per minute.

The development of the Automobile engine has not been so rapid as might be expected. The slow progress is mostly due to the fact that it is rather difficult to take care of the auxillary apparatus, such as air compressors, oil pumps and compressed air reservoirs. These apparatus together with the engine form rather a bulky arrangement. This is the chief objection to Diesel Automobile engines. Although the Diesel Automobile engine is still in the experimental stage, it does not seem very promising as compared to the simple gasoline engine run on the Otto cycle.

Diesel Locomotive.

The first Diesel-engines locomotive to be built was turned out of the works of Messrs. Sulzer Brothers, at Winterthur, in the early part of the year 1912. It took over five years to construct the locomotive. On account of the difficulty in starting and maneuvering, and also on account of the limitation of space and weight, the problem of its construction was very difficult and tedious.

"Figure 49 shows the design of this locomotive." "It is 54.5 feet long over the buffers and has two buggies of two axles each (I-I), and two driving wheels (2-2). The latter are

not directly coupled with the engine but indirectly with the blind axle (3) which is likewise the crank-shaft of the Diesel engine. (4).

"The Diesel engine is an ordinary two-stroke cycle engine with four cylinders (4) coupled in pairs under an angle of 90 degrees. This position gives complete balancing of the moving masses, the first and important condition when such engines are put on a movable platform. Between the working cylinders are placed two scavenging pumps (5) driven by levers from connecting rod. Beyond the engine in the roof of the car is placed the muffler (6). On the right of the engine stands an auxillary engine (7). This latter consists of twostroke cycle cylinders (7-7) coupled to horizontal air pumps (8-8) driven by these cylinders. The cooler for the air compressed by these pumps is indicated at 9. These engines serve to increase the power of the main engine when starting, maneuvering, and going up hill, in such a way that auxillary compressed air and auxillary oil-fuel are conducted into the main cylinder, by which means the diagram is enlarged, making the engine as elastic as a steam engine. For the current running of the locomotive the main cylinder works like the ordinary Diesel engines without the help of the auxillary. To the right of the engine is placed a battery of air cylinders (10), which help the action of the auxillary engine and which can be refilled by the auxillary engine at times when the latter is not used.

The two pumps (II-I2) provide for the water circulation in the cylinder jackets. Apparatus for the back cooling of the water by evaporation is indicated at I3, and at I4 the tank for water and fuel. A small donkey boiler at I5 is for heating the train. The channels I6, under the roof, lead the fresh air to the suction pipe of the different motor and pump cylinders. The whole plant is contained in a closed engine room,which makes the locomotive look from the exterior like a steel car."

"The engineer can operate equally well either end of the locomotive,as the engine is arranged to run in both directions.

The total weight of the locomotive in service is 85 tons. Figure 50, gives the details of the car construction.""

Trials have been made of this locomotive. The speed varied from I2 to 60 miles per hour. The change over from air to oil-fuel was accomplished satisfactorily without any trouble,at a speed of about 6 miles per hour,and the reversing arrangements proved equally successful.

The success of the Diesel locomotive can only be proved after a few years of actual service. The steam engine is so well adapted for locomotives that it is hardly possible that the Diesel locomotive will ever replace it.

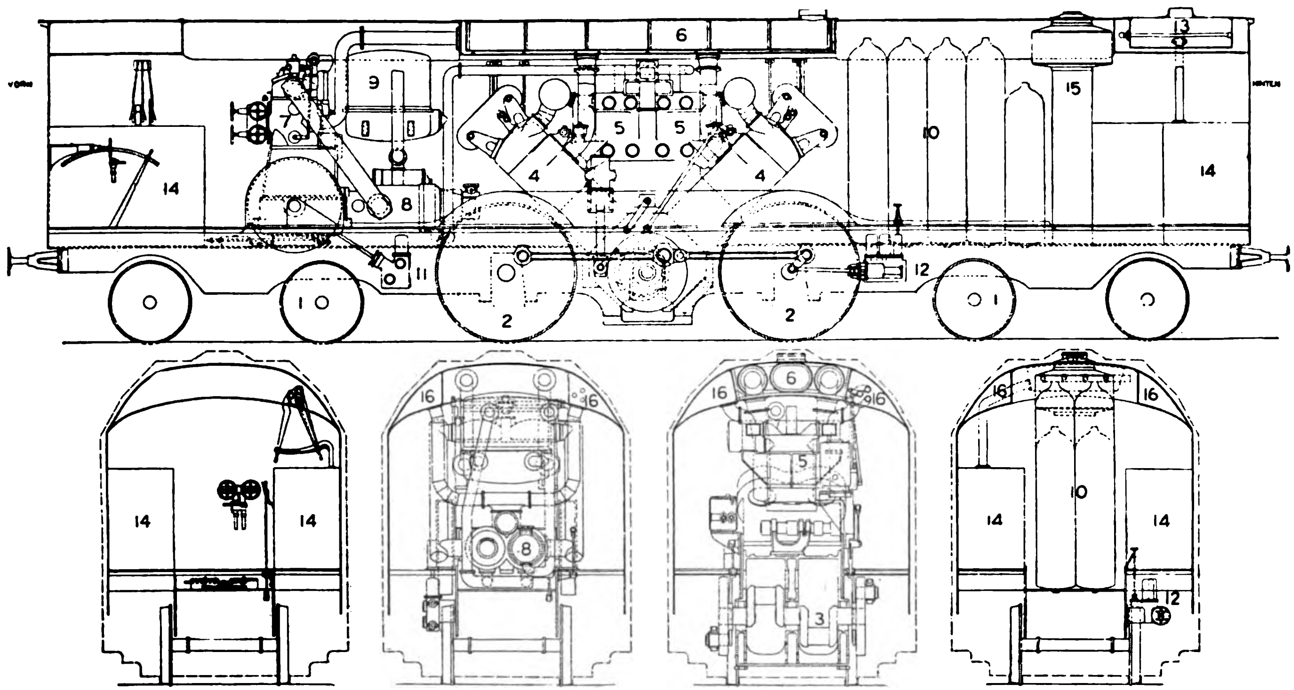


FIG. 50 SECTIONAL VIEW OF DIESEL LOCOMOTIVE SHOWING CAR CONSTRUCTION

THE INDUSTRIAL IMPORTANCE OF THE DIESEL ENGINE.

The fact that the Diesel engine can burn almost any kind of fuel is a great benefit to mankind. It has made use of the vast quantities of crude oils,which had practically been worthless, or at least had not been made use of until the Diesel engine made its appearance. The Diesel engine has become for all liquid fuels what the steam engine and gas engine are for coal. With the utilization of the crude oils it has practically doubled the resources of fuel for power production.

The utilization of the crude oils for power production,has influenced the very rapid growth of the oil industry. New oil fields are constantly being opened up. Recent geological researchers have not only proven that there is more liquid fuel on the globe than coal,but that it is more conveniently distributed with regard to geographical positions. The rapid demand for crude oils within the last few years has caused a rapid increase in their price. This, however ,is not due to scarcity of oils in the market,but to the fact that the oil industry is controlled and owned by only a few men who set the prices.

As tar and tar-oils are from three to five times better utilized in the Diesel engine than coal in the steam engine,a much better and more economical utilization of coal is obtained if, instead of being burned under boilers on grates in a wasteful way,it is first transformed into coke and tar by distillation.

The coke can be used for heating and metallurgical purposes, and from the tarry distillate valuable by-products can be extracted before the tar is burned in the Diesel engine. This method of utilizing coal is making a rapid progress in European countries. The Diesel engine also burns vegetable oils very successfully. This may not have any importance at the present time, or at least not in oil and coal producing countries, but it may be of importance in the future. France at one time thought of testing the application to power production of the earth-nut, which grows in considerable quantities in their African colonies, and which can be easily cultivated there. In this way the colonies could be supplied with power from their own resources, without being compelled to buy and import coal or liquid fuel. The earth-nut oil has been found to work very successfully, and it is found to be nearly as effective as mineral oils.

Experiments have also been carried on in Russia using castor oil and animal oils as fuel, and excellent results have been obtained.

FUELS FOR THE DIESEL ENGINES.

Although the Diesel engine was originally designed to burn coal,only fuel-oil has been principally used up to the present time. Nearly all kinds of mineral,vegetable,and animal oils can be burned successfully in the Diesel engine. Professor Constain,at the Swiss Testing Labortory,which is located at the University of Zurich,has undertaken the examination of the qualities and composition of all liquid fuels which can be used for Diesel engines. His investigations include the following points:#

I. Physical properties,such as:

(a) Properties when cold.

(b) properties on heating(boiling-analysis).

2. Chemical properties,such as:

(a) Chemical constituents.

(b) percentage of water and ash.

(c) Calorific power.

From tests and examinations already made,power oils have been divided into the following three classes:

I. Normal oils which can always be used:

(a) Mineral oils freed from benzine(gas oils)

(I) Hydrogen over IO percent.

(2) Calorific power over I8,000 B.t.u's.per lb.

(3) No solid impurities.

(b) Lignite tar oils.

(I) Hydrogen over IO percent.

(2) Calorific power over I7,460 B.t.u's per lb.

\# Taken from "The Diesel Oil Engine" Rudolph Diesel Institute of Mech England,Mch.,I912.

(C) Fat oils from vegetable or animal sources,such as earth-nut oil,fish oils, ect.

Data for reasearches lacking.

2. Oils which can be used only with the aid of special apparatus:

(a) Pit coal-tar oil.

(b) Vertical-oven,water gas and oil-gas tars,probably also coke oven tars.

(c) General Characteristics:

Hydrogen not over 3 percent.

Amount of free carbon not over 3 per cent.

Residue on coking not over 3 per cent.

Calorific power not under I5,480 B.t.u's per lb

3. Oils which cannot be used:

Tars from horizontal or inclined retorts.

It must not be understood that these oils will not be used in Diesel engines under special conditions.

OPERATION OF THE DIESEL ENGINE.

Starting of the Diesel engine.

Various methods have been proposed for the starting of the Diesel engine,but up tp the present time compressed air has chiefly been used. Electricity has also been used and found to work successfully,but it is not so much used as compressed air. The compressed air is obtained by any ordinary air compressor,which can be either directly connected to the Diesel engine or run separately by an auxiliary engine. Storage tanks are used for the storage of the compressed air and are directly connected to the air compressors and also to the cylinder of the engine. Various methods have been adopted for admitting air to the engines and cutting it off after it has done its duty. In practically all cases special mechanically operated air admission valves are fitted in the cylinder cover. These can be put into or out of action as required, by means which are more or less simple. In some cases the operating gear is interlocked with that of the fuel admission valve,so that only one can be operated at a time,and a single lever only is required. In one case the two are separated independently, so that compressed air can be used for a short time simultaneously with the fuel in order to give a temporary increase in power. Some arrangements are also made for shutting the air off from only half of the cylinders at a time so as to ensure that half shall have taken up the work of the oil before the

air is completely shut off. There are so many of these starting devices which differ principally in the mechanical construction that only one will be described. In Figure 5I,is shown the Sulzer starting gear used for Marine Engines.

"In this arrangement,the movement of the starting lever A to the left,turns the eccentric sheave B on the cam-shaft, so that the nose C of the cam will come into contact with the roller on the rocker D of the starting valve and set the engine in position for running ahead. At the same time the disc E is rotated and depresses a roller on a spring controlled rod which through a trip gear opens the air admission valve on the pipe, so that the engine starts on air. When fairly under way,the lever A is pushed further over into the running position; the trip gear comes into action and allows the spring rod to fall again and close the air valve,and pushes the nose C out of reach of the starting valve rocker,and at the same time allows the suction valve of the fuel pump to operate,so that the engine starts on oil. Movement of the lever A to the right, brings the nose F of the cam into contact with the rocker D,and the same sequence of events puts the engine running in the opposititе direction."

This double eccentric cam,shown in Figure 5I,has been abandoned by Sulzer Brothers within the last year,and they have adopted a new plan. "The plan is to mount rockers of the fuel and air-starting valves on a common shaft,but not on a common center. Thus, a rotation of the shaft by means of a lever on the starting platform lifts the pivot of one or the ot-

her of the rockers to such a point that the roller at the outer end is carried beyond the reach of the cam,so that the valve becomes inoperative,the roller of the other rocker becomes simultaneously lowered on to the cam. This arrangement takes no account of reversing,the position of the rockers being the same for ahead and astern,but it provides a neutral position with both the rollers clear of the cam,so that the latter may be shifted if required for reversing. This arrangement has practically become standard for all stationary engines."#

The starting of the Diesel Marine Engine."
Engineer (London) Jan.10,1913.

Starting Gear.

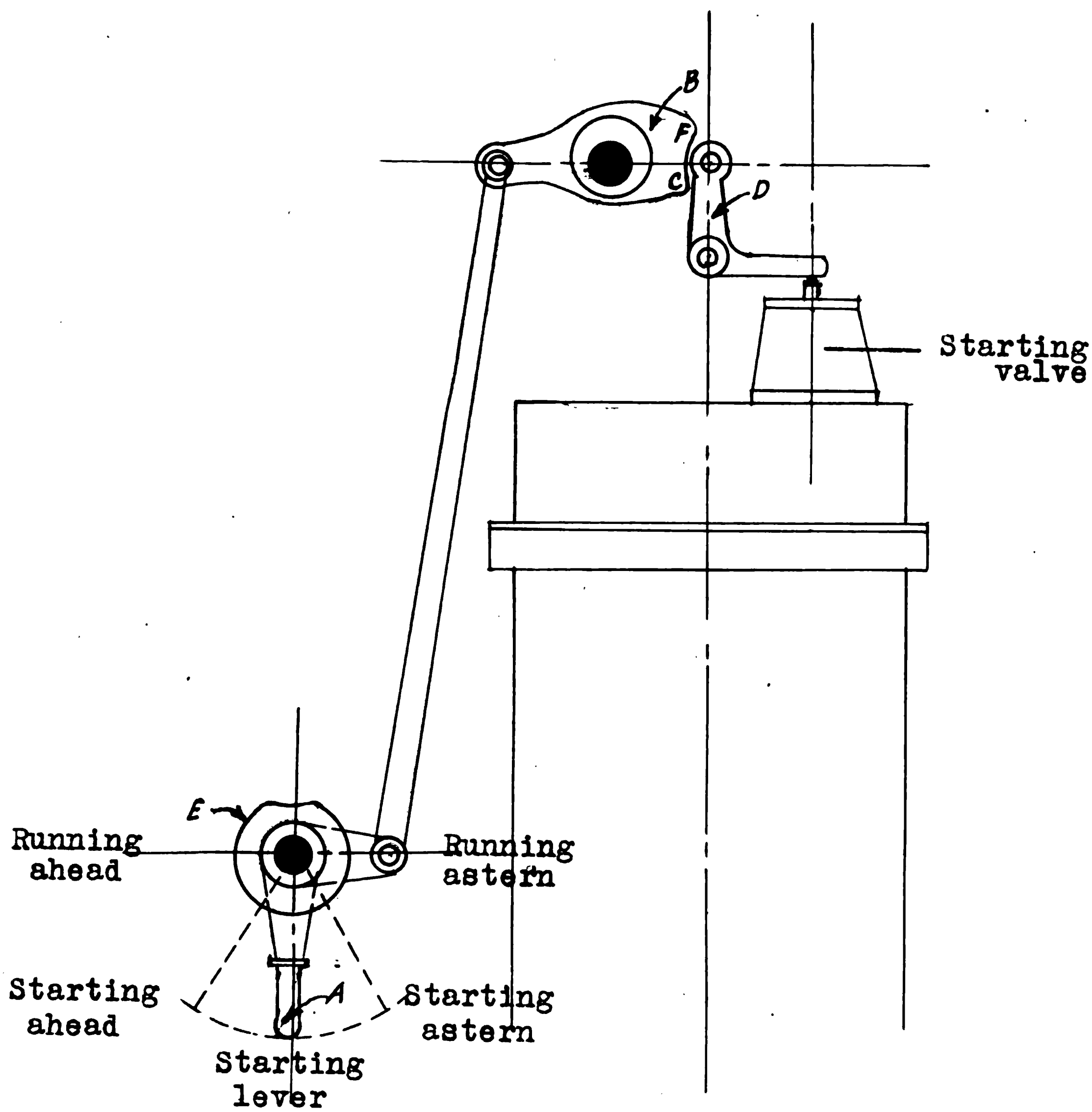
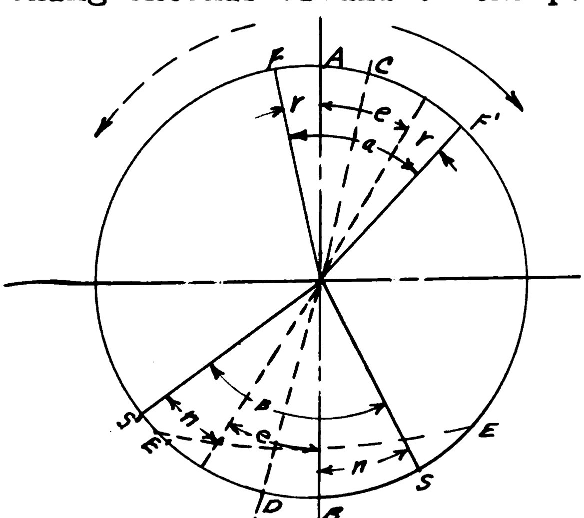


Fig. 51. Sulzer Starting Gear.

REVERSING THE DIESEL ENGINE.

As there are very few four-stroke reversible engines built, only the reversing of the two-stroke cycle will be explained. "It will perhaps facilitate the description of the mechanical operation if the various valve openings and closings, which require to be manipulated before an engine of this type can be reversed,are first explained."

"The exhaust is governed both as to its opening and closing, by the passage of the piston itself over ports in the cylinder walls,the crank position at the moment of opening being represented by the point E in Figure 52,for an engine running in the direction indicated by the full line arrow. The port opening extends around to the point E, and is equal on each side



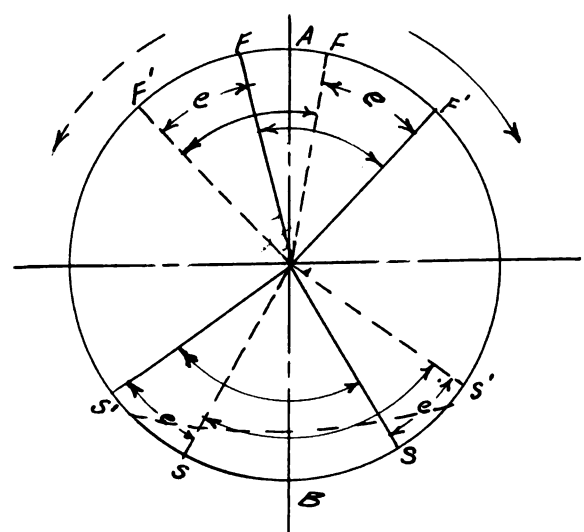


Figure 52. Valve Diagram Figure53.

of the center line AB,that is,it is correct for either direction,and so need not be further considered. There remain then the fuel valve and scavenging air valves. The crank position at the moment of opening of the fuel valve is represented by F in Figure 52,the opening extending around to F,while S-S are

the corresponding positions in connection with the scavenging air valve. The diagram shows that each of these valves has a certain "lead-angle" of opening,represented in case of the fuel valve by N,and it can be seen that before the engine is in a condition to run in the reverse direction,it will be necessary to reverse these "lead-angles" and place them on the opposi-tite side of the center line AB. Even though these "lead-angles",and also the duration of the opening,are of quite dif-ferent magnitude in these two valves,this reversal is effected in the following manner by a single dog-clutch,which has a cer-tain amount of play between the driver and the driving face, coupled on the vertical driving shaft. It will be seen from the diagram that the total angle of opening a of the fuel val-ve is made up of twice the lead angle e,while the total angle of opening b of the scavenging valve is made up of twice the lead angle or plus angle,so that we have the latter angle e common to both. It will further be seen that if this angle e is bisected by the line CD,the angles a and b,and equally the angle e,lie symmetrically about CD. Provided then that fuel and scavenging valve cams are arranged symmetrically about the line CD,with the length of the nose of each suitable to the respective periods of opening F-F,and S-S,it follows that the actual alteration of the position of the cam-shaft in relation to that of the crank-shaft necessary to place both valves in proper relationship to the latter to give reversal, can be obtained by a single movement of the cam-shaft through the angle e. The diagram in Figure 53,shows the full lines

for ahead,and the dotted lines for astern,the respective openings of the two valves when varied by the movement of the camshaft through this angle e."#

GOVERNING DIESEL ENGINE.

The fuel is pumped into the casing of the fuel valve by means of an ordinary plunger pump,the quantity pumped being regulated by the governor. If the load on the engine is increased,the speed will fall slightly and the governor weights will then move outwards,in so doing,by means of a link mechanism,the fuel pump is caused to deliver an increased quantity of oil to the cylinder,thus giving more power to meet the load. If the load is reduced,the engine speed increases,the governor weights open out,and the quantity of oil delivered by the fuel pump is reduced. The duty of the mechanism of the governor is to hold up the suction valve of the fuel pump for a greater or less portion of the delivery stroke. As long as the suction valve is held up ,no oil is delivered to the fuel valve casing,but is delivered back into the suction of the pump. When the suction valve is allowed to seat itself,the remainder of the oil contained in the pump barrel is discharged into the fuel valve casing and is ultimately blown into the working cylinders.

Some makers of the Diesel engines use one fuel pump for each cylinder,and others use one pump for all cylinders. Where a

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#"Some Impressions of Continental Marine Diesel Engine Practice."

Engineer (London) Dec. I5, I9II.

fuel pump is used for each cylinder,they are combined in one casing and operated by the same eccentric on the cam-shaft,and the fuel delivered to each of the cylinders is controlled by the same governor. Where one pump is used for the engine a distribution box is used,into which the oil is pumped and distributed for each cylinder. The difficulty with this arrangement is that each cylinder does not get the same amount of oil and, therefore,cannot do the same amount of work;also if the outlets are so adjusted that at one particular load the cylinders are doing an equal quantity of work each,this proportion will be upset if the load changes.

ATOMIZATION OF FUEL.

The success of the Diesel engine depends a great deal on the proper distribution of the fuel in the combustion chamber of the cylinder. A typical atomizer or distributer used on European engines is shown in Figure 53. "A series of plates b, arranged just below space S,around the injection valve guide g,are provided with small holes in such a way that they straddle each other from plate to plate. These plates help to retain the oil after having been deposited in space S,while the holes will equally distribute it and mechanically divide the blast of injection air into small streams,thus disintegrating the fuel passing down through them. By means of passage n, arranged in the circumference of plug I,these streams are directed into the injection nozzle m,where they acquire their maximum velocity.

The resistance of the oil against the abrupt acceleration thus produced causes the oil to be disintegrated into small particles, which are carried directly into the body of highly heated air in the combustion chamber."#

On the American Diesel engine a horizontal atomizer is used. These are arranged horizontally on the side of the combustion chamber. Owing to this horizontal position particular care must be taken to distribute the oil equally around the circumference of the injection valve. A sectional view of the atomizer is shown in Figure 54. "Oil and injection air come together in space S; the oil entering along passage a, and annular ring space r, through a ring of holes h. As the injection valve n opens, air and oil, being divided into small streams by a circle of holes p, are forced into the injection nozzle m, where these streams impinge upon each other, thus atomizing the fuel."#

LUBRICATION.

For lubricating the cylinders, special small oil pumps are provided. The oil is injected on the piston when it is at the bottom of the stroke. For bearings, connecting rods, etc., forced lubrication is generally used. The pump for the forced lubrication is driven direct from the shaft, and may be a piston or cog wheel pump. The engines fitted with forced lubrication are totally enclosed, the dripping oil being gathered in the bed plate and sucked up again by the pump, after having passed through filters and coolers.

From "Oil Engines," by H.R.Setz.
Mechanical Engineer. Oct.27, 1911.

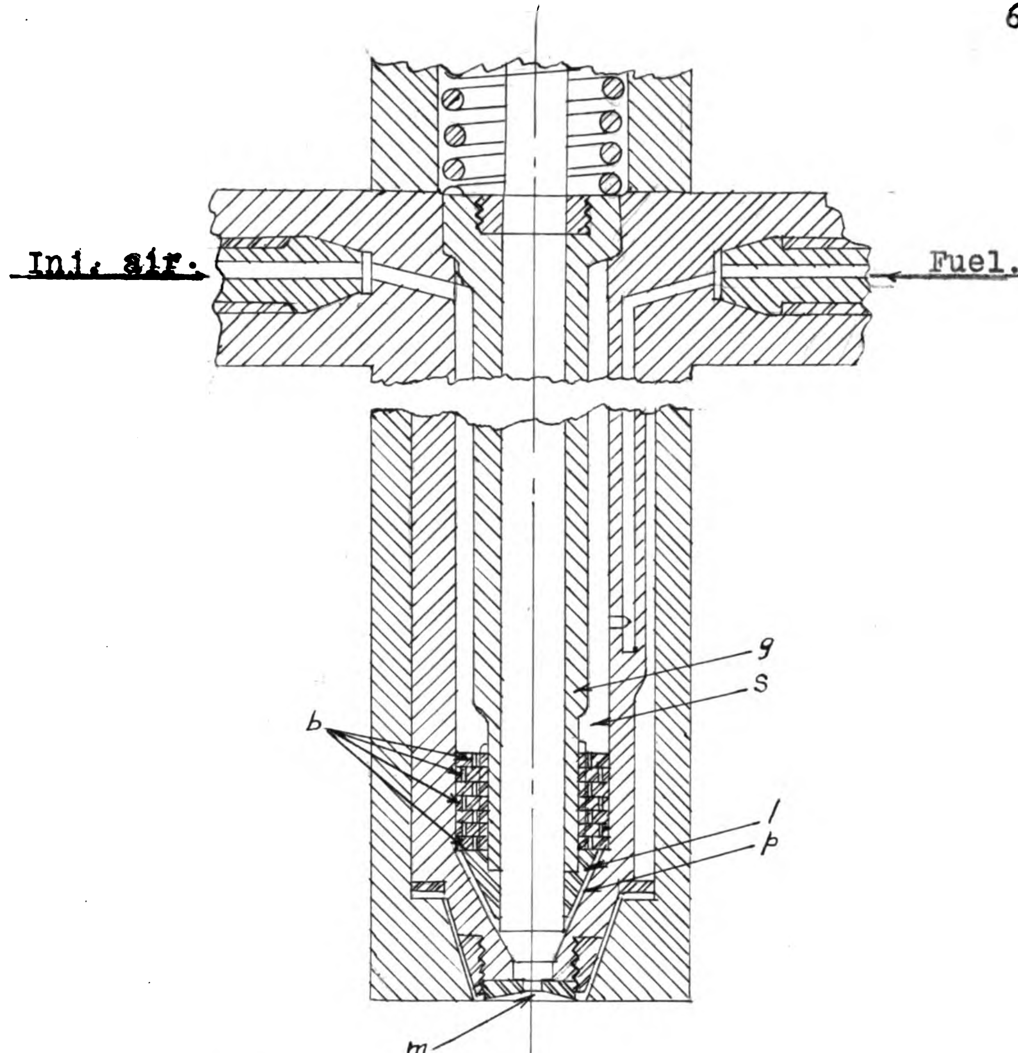

Fig. 53 European Atomizer.

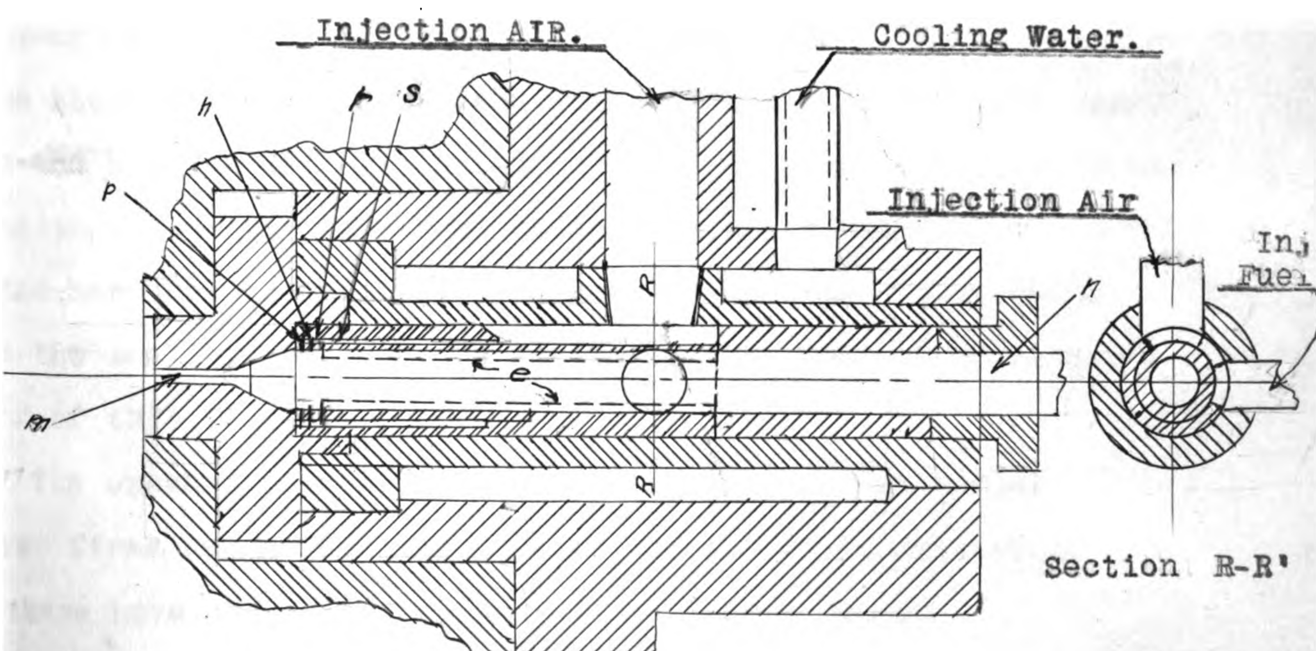

FIG.54, AMERICAN ATOMIZER..

Oil holes are bored in the shaft and connecting rods,which take the oil from the bearings up to the respective crosshead pins and other places where lubrication is required.

COOLING.

The cylinders are always cooled,and also the pistons when above a certain size. The water is generally led to the engine by gravity and only under a small head. For piston cooling several solutions are possible. In most cases a telescopic arrangement is provided. The disadvantage of this solution is the necessity of providing a stuffing-box to prevent leaking water from getting into the bed plate and mixing with the lubricating oil. In other devices joints are made use of. These are subject to similar disadvantages. A simple arrangement is that in which the water does not entirely fill the cooling space of the piston,the water being only squirted against the highly heated surfaces and drained off through a pipe which surrounds the spray pipe. By this method the stuffing-box is done away with,and all additional pressures and strains are eliminated. Some firms use oil for piston cooling,which may have some advantages,but which,on the other hand,has the disadvantage of a smaller cooling effect owing to the smaller heat and the smaller coefficient of transmission of this liquid.

The exhaust valves for smaller engines are not cooled. Some firms use no cooling devices for larger engines,while others have the larger exhaust valves water cooled.

SCAVENGING.

For the two-stroke cycle engine the exhaust valve is dispensed with. The piston at the end of its outward or downward stroke uncovers slots arranged in the cylinder walls through which the burnt gases escape from the cylinder. By means of a special scavenging pump an air pressure of about four pounds per square inch is produced. This lightly compressed air enters the cylinder through a valve arranged in the cylinder cover,drives the burnt gases out of the cylinder,and fills the latter again with a new charge of air as soon as the piston in its upward motion covers the slots. The air valve being closed,the air is compressed in the compression chamber. The whole process of driving out the gases and refilling the cylinder takes place within a very short time at the end of the outward or downward stroke of the piston. The ordinary length of the slots is about one-fifth of the stroke. The disadvantage of this system is the weakening effect on the cylinder produced by placing the scavenging valve in the cylinder cover.

To overcome this,some manufactures use half of the exhaust ports on one side of the cylinder for scavenging ports.

The scavenging air then enters the cylinder through ports on one side,driving the burned gases out through the exhaust ports on the other side. This system is very simple,but it also has its disadvantages . To obtain good scavenging,baffle plates are placed on the piston head which destroy the combustion chamber for perfect combustion. It also has an equal cooling

effect on the piston head and cylinder walls which causes great strain and very often rupture. A combination of these two systems is also used ,but it is so much more complicated, and has no advantages,so that it has met with very little favor.

PISTON SPEEDS.

"The different working conditions of the Diesel engines naturally require different types. The piston speed is generally between 600 and I,000 feet per minute,which cannot be reduced below a certain limit,as otherwise the slightest leakage could prevent the compression attaining the required amount."

"The piston speed can,however,be as low as I80 to 200 feet per minute for continued service. For standard slow-speed single-acting four-cycle engines the number of revolutions lies between I50 and 300 at respective capacities of I,000 and I5 horse power. These engines have the best fuel consumption ,but have also the disadvantage that they are heavy and expensive. For this reason a single-acting multiple cylinder high speed four-stroke cycle engine has been designed,which is especially suitable for direct coupling to dynamos. The speed varies between 220 and 350 revolutions per minute,at units varing between I,000 horse power and I00 horse power. For very small auxiliary engines up tp about I00 horse power the speeds range from 400 to 600 revolutions per minute and even higher."

"Single-acting two-stroke engines with outputs ranging between 700 and 3,000 horse power are carried out with speeds of 160 to 140 revolutions per minute."

" For ship propulsion there is a tendency to use lower speeds in order to obtain good propeller efficincy. Speeds ranging from 100 to 350 revolutions per minute may be taken as limits for sets of several 1,000 horse power down to 100 horse power."#

" #Modern Diesel Oil Engines." by F. Schubeler.
Mechanical Engineer, July 28, 1911.

DIESEL ENGINE COMPARED WITH STEAM AND GAS ENGINES.

INDUSTRIAL PLANTS.

Since the Diesel engine first made its successful appearance in 1897, it has a great field in industrial plants, and has won great favor with European engineers.

The main advantage of the Diesel engine over steam and gas engines may be summed up as follows:#

1. "Its extreme economy in fuel consumption over a wide range of load, and the entire absence of stand-by losses.
2. "Its ability to use a safe, cheap, compact form of fuel, in shape of high flash-point residual oils, obtainable in large quantities all over the world."
3. "Its freedom of pre-ignition, due to the fact that air only is compressed and not a mixture, thus eliminating a not infrequent cause of breakdown in other forms of internal combustion engines."
4. "No carburetors, vaporizers or troublesome ignition devices are required."
5. "The engine can be started up when cold and load put on in one minute; and is ready for any load up to its capacity at any moment."
6. "Small floor space as compared to steam plants and gas producer plants.
7. "Lastly, one of the most important features is its great reliability, even when running for long periods, with variable conditions of load."

From "The Application of Diesel Engines to Land and Marine Work," by D.M. Bright, Canadian Engineer, Nov. 7, 1912.

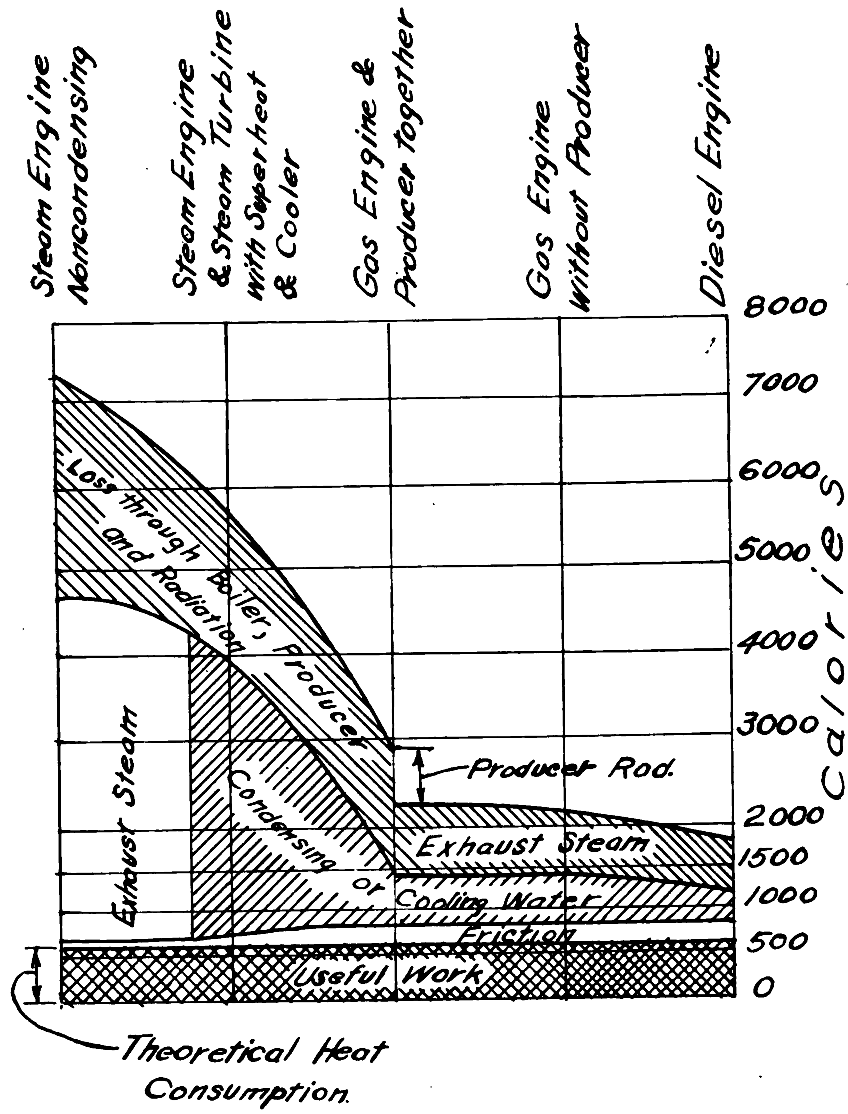

Fig.-55, Heat Distribution of Different Types of Plants.

In Figure 55,is shown the heat utilization for I lb. h.-p-hr. in the different prime movers now known,and the following table gives the thermal efficiencies of different prime movers:

Steam,ordinary,as low as 6 per cent; highest,including superheated, etc.,I5 per cent.

Hot air engine, from 7 to IO per cent

Oil engine, ordinary,I6 to 20 per cent.

Gas engine, 20 to 25 per cent,

Diesel engine,30 to 40 per cent.

It is rather difficult to give comparative cost of running power plants due to the fact that very few manufactures prepare and publish their power cost accounts on uniform bases,except in the case of electric-supply stations. In table I,are given average results obtained from various plants in Great Britain, not exceeding I,000 h.p.

Table I- Average Cost in Cents per B.t.u. Sold.#

Type of Engine	Fuel	Lubrication Oil,waste Stores & Water	Wages	Repairs & Mainte-nance	Total Work Cost	Load Factor
Steam	0.9I	0.I2	0.505	0.525	2.06	I4.77
Gas	0.87	0.I8	0.565	0.485	2.I0	I5.3
Diesel	0.46	0.08	0.384	0.I4I	I.07	I4.3

Owing to there not being as yet large electricity supply stations equipped solely with Diesel engines or gas engines,

From "The Diesel Oil Engine" by C. Day.
Mechanical England,(London) Sept. 8,I9II.

the limit of I,000 horse power has been fixed. From the averages it is clear that a substantial gain is obtained by the adoption of Diesel engines as against either gas or steam engines.

It is also noticable that the gain is not only on fuel consumption but it is practically in the same proportion on the other items of expenditure. In many cases the Diesel engines have shown over extended periods,a saving of 50 to 60 per cent, and some cases an even greater percentage,the result being due to the fact that the Diesel engines average working results were very much nearer to the guaranteed figures than with gas or steam engines,combined with the fact that the relatively high cost of working at light loads with gas or steam,had not been sufficiently taken into account when considering the guaranteed figures.

Table II-Average Cost in Cents per B.t.u. Sold, on Steam Stations of Different Sizes.#

Capacity Station not Exceeding	Fuel	Lubrication Oil,Waste, Water & Stores	Wages	Repairs and Maintenance	Total	Load Factor
250 KW.	I.27	.I80	.705	.725	2.90	I3.2
500	I.I3	.I2I	.545	.585	2.38	I3.3
750	.87	.IOI	.465	.485	I.9I	I5.4
I000	.8I	.IOI	.465	.425	I.80	I6.8
I500	.85	.08I	.342	.364	I.64	I6.9
2000	.75	.08I	.323	.423	I.57	I7.7
3000	.67	.08I	.303	.344	I.39	I7.4
4000	.8I	.060	.284	.404	I.55	I8.8
5000	.785	.060	.2IO	.323	I.29	I8.7
7000	.725	.08I	.263	.404	I.47	I7.9
I0000	.525	.060	.I80	.263	I.03	22.6
20000	.605	.060	.224	.324	I.2I	I9.6
50000	.465	.040	.202	.220	0.925	20.56

From "The Diesel Oil Engine",by C. Day.
Mechanical Engineer,(London),Sept.,8,I9II.

In Table II, is shown the great improvement which follows increase of size with stations,or,expresses in the reverse direction,it shows how great is the disadvantage of small stations when steam power is used. It is also noted that even with the largest steam station,the cost per unit generated,is no better than for quite small stations using Diesel engines. This shows how cheaply current can be supplied by small stations which had before only been obtainable by large stations where the demand was great. In all cases the figures which have been given do not include anything for interest on capital or depreciation.

As there are so many variable factors,it is hardly possible to give definite statements showing the cost of constructing and equipping power houses of different types. Mr. Charles Day,of England,has made a considerable number of estimates up to a capacity of about I,000 KW.and he has found that there is generally very little difference between the gross capital expenditure,whether steam,gas,or Diesel engines be adopted.

Table III.-Some Comparative Results of Steam,Gas, and Diesel Engine Plants,The Results of Which are Compiled by Machenenfabrik,Ausgburg-Neurnberg Co.Load Factor I00. The plant considered comprised two sets,one of 600b.h.p. and the other of I50 b.h.p.#

	Diesel	Steam	Gas
First Cost.	$33.370	$32.480	$45.200
Cost per B.H.P. including Capital,Charges & depreciation	$ 0.348		$ 0.359

#From "Internal Combustion Engines Working on the Diesel Principle" by H.L.Howard,Mechanical Engineer,July I4,I9II.

Oil at $ 9.70 per ton.

Coal at $2.18 per ton.

Coke at average of $2.06 per ton.

In Table V.are figures obtained by Captain Sankey,in comparing the Diesel engine with other prime movers,having a normal load of 200 brake hprse power.#

TABLE V.

	Total Annual Cost.
Non-condensing Steam engine	$7050.
Condensing Steam engine	$5140
Over-type superheated engine	$4270
Gas engine with pressure plant	$4840
Gas engine with suction plant	$4900
Oil engine	$5140
Diesel engine	$4540

From the data obtained it is seen that the Diesel engine for small and medium sized power plants is the most efficient prime mover available.

MARINE POWER PLANTS.

The advantages of an oil engine for marine work over the steam are many,and the important points may be summed up as follows:

1. "Space occupied only 60 per cent in comparison with steam."
2. "Reduction of fuel cost over steam engines."
3. "No stand-by losses;steam 15.2 per cent of fuel consumption."

#"Taken from "Heavy Oil Engines"-Captain Sankey, Engineering,London,May 31,1912.

4."Water required for cooling,half of that required for condensing purposes."

5."Minimum of labor and time in replenshing fuel."

6."Practical elimination of firemen and trimmers ."

7.Considerable reduced fuel space giving increased cargo space."

8."Weight of machinery much less than steam."#

Having enumerated the advantages of the Diesel engine,it might be well to give some of the disadvantages:

I."Diesel engines are dependent upon compressed air to effect reversing and starting."

2."An extra good bed or sole plate is required on shipboard,the vibration being in excess of steam."

3.Fairly high revolution engines."

4."Failure of compressed air supply would cause inability to start or reverse."

5."Engines are not generally so easily handled at low speed as steam."#

Taking all the economies effected in weight of fuel,weight of machinery, and engine room space,it may be safely estimated that the extra cargo which could be carried would be about I5 per cent of the displacement of the vessel. In a comparative estimate made,it has been shown that a vessel of about 5,000 tons,the net saving between the Diesel engine and steam,worked out to be about $5.500 per annum.

Modern Developments in Oil Engine Practice.-by E.Shackleton. Mechanical Engineer, Sept.,I,I9II.

The cost of the Diesel plant is found to be more expensive in installation than that of steam. This expense ranges from 15 to 20 per cent, including all auxiliaries in both cases.

Below are given comparative costs of steam and oil engines, which are based on prices in Europe:#

STEAM ENGINE.

Fuel--Coal	Labor	Fuel	Stand-by losses.
1,500 i.h.p. times $1\frac{1}{2}$ lbs.per i.h.p. equals 2,250 lbs.	10 Firemen Trimmers & One Donkey-man. $.24 per day per man: $2.55 per day for food. 7 days per week: $18.75 Wages $4.86 per week each equals $53.50	24 tons 2 cwt.per day at $3.40: $81.80 $572.00 per week.	Assumimg 20 days per annum, 5 tons per day, equals 100 tons, equals $341.00 per annum say, $6.60 per week
	Total sum----	$18.75 53.50 572.00 $644.25.	

From "Modern Developments in Oil Engine Practice." by E. Shackelton, Mechanical Engineer. Sept.1,1911.

OIL ENGINE.

Fuel--oil.	Labor.	Fuel	Stand-by Losses
I.500 B.h.p. I.725 i.h.p. I,500 times ½lb.:750lbs per hour.	I Donkey-man at $4.86 per week. Food $.24 per day: $1.68 per week:$6.55.	7 tons I6 cwt.per day at $9.76 per ton:say $76.95 per day or $538.20 per week.	none
	$538.20 6.55 Total-- $544.75		

CARGO SPACE SAVING COMPARED. OIL vs. STEAM.

	Steam	Oil
4,000 ton vessel	none	4% of 4,000 tons,values,say,at $4.86 per ton,per annum,equals $7,760.00.

"Mr. Davidson in England has calculated the effect of replacing the steam engine by a Diesel engine on the Destroyer, Paul Jones,of 400 tons displacement,8000 i.h.p. engines,as follows:#

	Steam	Oil.
Weight of engines...............	449,000 lbs.-	317.00 lbs
Weight per b.h.p.....................	64 lbs.	44 lbs.
Radius of action at IO knots & I80 tons of fuel...............	I700 knots	I0,000 knots
Radius of action at 28 knots & I80 tons of fuel	630 knots	2,950 knots.

From "The Present Status of the Diesel Engine,"by Rudolph Diesel.

	Steam	Oil.
Fuel per b.h.p.--hr. at 20 knots..	2.34 lbs------	-0.5 lbs
Engineers and Stokers..............	54-----------	2I
Fuel consumption in I yr.(20,000 marine miles)..................	2,I00 tons----	--360 tons
Cost of fuel....................	$3,840	$924.
Cost of engine-crew labor........	4,500	$I,920
Cost of repairs.................	2,000	400.

As to wear and tear,the Diesel engine may be slightly higher than the steam engine,but as it is impossible to have steam engines without boilers,and as the latter put up the repair considerable,the oil engine is in the long run,considerably under steam in repair costs. Accidents caused by burst air reservoirs are extremely rare,and it must be recognized,that whether the motive power be steam,gas,or oil, accidents in one form or another will occur,and under all ordinary conditions there is far less risk in explosion than with steam engines and boilers.

The life of the Diesel plant is about the same as that of the steam plant. By studying the various engines,it is seen that the Diesel is the most economical prime mover obtainable,and under most conditions, except for very large plants,it is impossible for the steam and gas engines to compete with it.

THE DIESEL ENGINE IN EUROPE.

The development of the Diesel engine in Europe,within the last few years has been very marked,and great strides have been made. The unparalled progress of this prime mover,due primarily to the expiration of the basic Diesel patents,created a wave of enthusiasm,which swept over Europe in full-tide only a few years ago.

The larger Diesel engine of over 1000 h.p. has not developed as rapidly as the smaller engines,but they have proved to be a commercial success. In larger sizes the Diesel engine has to compete with steam and gas engines. The latter of which has caused to retard the development to a great extent.

The smaller and medium Diesel engines in sizes 40 h.p. in single cylinder units,and up to about 600 h.p. in four-stroke cycle units,play a vastly more important part in Europe.

It has unquestionably come to stay,and has reached a high degree of perfection which places it right in line with corresponding steam and gas engine plants as far as reliability and cost of operation are concerned,and far ahead of its competitors when considered from the standpoint of fuel economy.

It is surprising to note how many manufactures of gas and steam engines abroad have taken up the manufacture of the Diesel engine,because they found that the sale of suction gas producer plants has fallen off alarmingly within the last few years. The reason is plain. The single-acting,four-stroke

cycle engine,single or multi-cylinder Diesel engine, but particularly the former,is comparatively simple in construction and operation,especially when its unequaled efficiency is considered. This engine is always ready to be put in service at a moments notice and has no stand-by losses;it does not require up-keep and attendance of boilers and gas producers,and its cost compared with that of steam is reasonable. It can be installed in the basements of buildings below occupied dwellings,whereas in Europe boilers are not permitted in such places. One of the greatest advantages is the fact that the actual fuel consumption of Diesel engines,taken over long periods of operation,does not exceed the guaranteed figures,whereas,in gas producer and steam plants this excess is quite considerable. In a Diesel plant the skill of the operator must have much less influence upon the fuel economy than in steam or gas producer plants where everything depends upon the efficiency and intelligence of the fireman and producer attenant.

It is evident that in Europe where fuel prices are from two to three times higher than in this country,while labor is only one-half to one-third as much,the item of fuel cost constitutes a very large percentage of the total cost of power,particularly since the other items,such as interest and depreciation, attendance and repairs,are actually much lower and thus form a still smaller percentage of the total cost. Taking all points into account it is seen that the Diesel engine is entirely favorable for European countries,which fact has brought about the rapid and wonderful development of the Diesel engine.

THE DIESEL ENGINE IN AMERICA.

Why the Diesel engine has not been used more extensively in this country is a question often raised. Although there are more of these installations than generally supposed,the number of Diesel engine plants is comparatively small. Many have tried to account for this by asserting that workmanship here is inferior to that in Europe and that the operators are less skilled. Dr. Diesel,however,during his visit to America in I9I2,refuted this statement. He claimed that the Diesel engines built in this country,after having passes the necessary apprenticeship stage,are quite as good as those of European makes;furthermore,they are handled inteligently. In his opinion,the question is purely economic. The following are Dr. Diesel's reasons for America being so far behind Europe in the development of the Diesel engines:

(a)"Coal is much cheaper than in Europe,and therefore, people are more wasteful with it. Whereas,the leading idea in America is economy in first cost. The word efficiency,which is the base of every contract with European people,seems to be unknown to a vast proportion in this country;not to engineers,but to business men and to buyers of engines."

(b)"In the same order of ideas,American steam engines are much cheaper than European engines,but the Diesel engine is not and will not be a cheap engine;it aims to be the best engine and must be constructed of the highest class

of materials with the most skilled workmanship. This makes it difficult for it to compete with this type of engine under the ideas which prevail. The people here are accustomed to engines of very low price, taken per pound, and the price of Diesel engines taken per pound seems exorbitant."

(c)"The lack of capital on the part of the prospective purchaser in many cases, and also in many cases the higher rate of capital interest prevailing in the American money markets."

(d)" In the last few decades the general business profits have been so large that people do not care for most economical methods of production and for the strictest economy in the fuel bill as well as other expenses, the ruling object having been to manufacture quickly and in quantities without regard to cost. America has not had to compete with the industrial countries of the world, as Europe has."

From these reasons it is seen that the American people paid very little attention to efficiency. Within the past two or three years, however, conservation and efficiency have been impressed upon American public to such an extent that it is reasonable to assume that more attention will hereafter be given to economy in production. This will undoubtedly open the field for the Diesel engine in this country, for the possibilities of development are nowhere any greater than they are in America.

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